Innovation capability building by the TVET sector for the Fourth Industrial Revolution in South Africa

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A research report submitted to the Wits Business School in the University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Management in the field of Innovation Studies

Johannesburg, 2023

ABSTRACT

This is a qualitative research report on Technical and Vocational Education and Training (TVET) system capability building for the fourth industrial revolution in South Africa. The study evaluated the level of complementarity amongst the main components and key role players within the Centres of Specialisation (CoS) program in relation to capability building. The foundational theories that guided this study include the Sectoral Systems of Innovation and Technological Relatedness.

An embedded case study involving welding and boilermaking CoS cases was used. Data were collected through scholarly and grey literature review, semi-structured and unstructured interviews of participants representing colleges, employer-partners and students that were on the verge of completing their program. A thematic analysis approach was used for analyzing the collected data, with guiding themes emerging from both the literature survey and primary data.

Despite employer-partners being one of the key role players for the learner development process, the study finds that past interventions and research efforts have largely been directed to colleges with little attention paid to industry firms. Even though some colleges have taken initial steps, none of the cases studied has fully integrated industry 4.0 (i4.0) technologies with their training programs. Employer-partners either are in the same position or have achieved partial integration. The study highlights complementarities that exists within the sector. Potential improvements are also outlined with regard to interaction and interdependency structures within the TVET sector. These offer possibilities for maximizing synergies among various 4IR capability building projects and capabilities that may exist within the whole TVET sector.

KEY WORDS

Sectoral System of Innovation, Fourth Industrial Innovation, Industry 4.0, Technical and Vocational Education and Training, Capability Building, Technological Relatedness, Absorptive Capacity

DECLARATION

I, Thulani Mngomezulu, declare that this dissertation is my own unaided work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in the field of Innovation Studies at the Wits Business School in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other University.

Signature: ……………………………………………………………..

On this …08th…………… day of …October……………………2023………..

Thulani Mngomezulu

Name

DEDICATION

To both my wife and our late daughter, Enhle!

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor Prof Geci Karuri-Sebina for all the support she gave from initial stages of the research until the finish. Thank you for your guidance, encouragements and always availing yourself even when it is difficult to do so. Special thanks also goes to all participants who contributed with various inputs towards this completion of this report. For your openness and willingness to put time aside to engage with me during your busy schedules, I thank you.

Dr. Diran Soumonni, our program director has shown highest level of passion and respect for the subject, guiding us each step through the entire course journey. Your compassion in most trying times was also much appreciated. The journey has been a major personal learning experience for me. Thank you sir.

My wife is one person who I believe has sacrificed even more than I have, for me to complete this program. Together we went through the worst of times but you maintained your full support throughout the journey. It is through you that I understand what true selflessness is. Thank you! To the rest of my family, thank you for your understand and support!

To God, for affording me strength and sufficient grace to complete this course, Thank you!

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LIST OF ABBREVIATIONS & ACRONYMS

3IR	Third Industrial Revolution
4IR	The Fourth Industrial Revolution
A21	Artisans of The 21st Century
AI	Artificial Intelligence
BRICS	Brazil Russia India China and South Africa
CAD	Computer Aided Drafting
CET	Community Education and Training
CHIETA	Chemical Industries Education and Training Authority
CNC	Computer Numerical Control
CoS	Centres of Specialisation
CPS	Cyber-Physical Systems
CSIS	Country-Specific Industry Structure
DHET	Department of Higher Education and Training
DSI	Department of Science and Innovation
DST	Department of Science and Technology
DTI	Department of Trade and Industry
ETDP	Education Training and Development Practices
FCAW	Fluxocord Arc Welding
FDI	Foreign Direct Investment
GVC	Global Value Chains
HREC	Human Research Ethics Committee
I4.0	I4.0
ICT	Information and Communication Technology
IIoT	Industrial Internet of Things
IoT	Internet of Things
IPAP	Industrial Policy Action Plan
IPPS	Institute for Post-School Studies

IPR	Intellectual Property Rights
LMS	Learning Management System
MNC	Multi-National Companies
MOU	Memoranda of Understanding
NACI	National Advisory Council on Innovation
NDP	National Development Plan
NOCC	National Occupational Curriculum Content
NRF	National Research Foundation
NSF	National Skills Fund
NSI	National Innovation System
OECD	Organization for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PLC	Programmable Logic Controller
PRO	Public Research Organizations
PSET	Post-Secondary Education and Training
QCTO	Quality Council for Trades and Occupations
R&D	Research and Development
RQ	Research Question
RSA	The Republic of South Africa
RTV	Robot Transport Vehicle
SETA	Sector Education and Training Authority
SIP	Strategic Integrated Projects
SIS	Sectoral Innovation System
SSI	Sectoral System of Innovation
TIA	Technology Innovation Agency
TVET	Technical and Vocational Education and Training
VC	Venture Capital

1. Chapter 1: INTRODUCTION

1.1. PURPOSE OF THE STUDY

This research seeks to establish how well the Technical and Vocational Education and Training (TVET) sector, through the Centres of Specialisation program (CoS), is configured to enhance capability building for the fourth industrial revolution (4IR). The focus of the study is on technological innovation capability and knowledge spillover paths between the TVET colleges, industry firms (and training institutions associated with them), and the impact on innovation capability building within industry.

1.2. CONTEXT OF THE STUDY

In a report published by the Presidential Commission on The Fourth industrial Revolution (2020), one of the four themes or pillars identified for the 4IR strategy is investment in human capital. Considering the prospects of future work, and acknowledging the legacy of unemployment and underemployment, which was previously explained as caused by the skills mismatch, the commission embraced the concept of Human Centered Agenda and recommended urgent restructuring of the human development ecosystem.

The TVET sector, which is a component of the Department of Higher Education and Training (DHET), forms part of the human capital development ecosystem in South Africa. There are currently 50 registered TVET colleges with 364 campuses spread across the country. The number of learners enrolled by the TVET colleges was reportedly sitting at 452,277 according to the DHET's 2021/2022 annual report. Work-based learning and continuing training, and professional development characterize the TVET system (NACI, 2021).

As part of initiatives aimed at addressing priority skills demand and capacitation of TVET colleges, the DHET launched the Centres of Specialisation (CoS) pilot programme in 2016. There are currently 34 registered CoS. These CoS are part of the 50 registered TVET colleges. The CoS program is structured such that different stakeholders contribute through four key components. These components include theoretical foundation, practical training, structured workplace learning and final assessments. The programme is centered on partnerships between colleges and employers, and is inspired by Artisan of the 21st Century (A21). A21 is a dual system approach adopted by DHET from Germany, which is characterized by integration of learning between the college and workplace.

1.3. RESEARCH PROBLEM STATEMENT

Olaitan et al. (2021) find South Africa to have a fall in digital technological readiness, low technological capability, and scarcity of both skilled workforce and technological infrastructure. The period to which this fall was attributed was not explicitly defined by the authors. However, this assertion was made after a review of literature and articles published between years 2014 and 2020. Skills deficit or mismatch in critical sectors has been cited by Industrial Policy Action Plan (IPAP) as one of the constraints to industrial and technological development for the country (DTI, 2018).

The TVET colleges are tasked with providing quality education in line with national and economic priorities (ETDP-SETA, 2021). This makes the TVET system one of the key stakeholders when addressing the above-mentioned challenges. Skilled work force is important for creation and implementation of innovation; and increases absorptive capacity (OECD, 2016). However, the sector is not without its own challenges. Limited access to workplace-based learning for students, technology and its use during the teaching process, are some of the challenges facing TVET colleges (DHET, 2020). These issues are hampering the ability for the sector to efficiently respond to the rapidly changing economic landscape. The technology and educational tool industry is emerging, but is not targeting the public education sector (OECD, 2016). The primary target for these high cost technologies is the more commercially attractive private (corporate) education sector (OECD, 2016).

Government initiatives such as Centres of Specialisation and others are expected to contribute towards the transformation of the workforce. It is imperative then to continuously assess how these projects are assisting the

TVET sector in effectively executing its mandate. The advent of 4IR further warrants a more innovative response to ensure innovative capability of the South African economy.

1.4. SIGNIFICANCE OF THE STUDY

South Africa has a noticeable drive towards transforming both the education and training sector, and the labour market for more productive and developing economy. The Education, Training and Development Practices - Sector Education and Training Authority (ETDP-SETA) for an example, has appointed the University of Johannesburg to carry out research work around the impact of 4IR on Education, Training and Development sector (ETDP-SETA, 2021). DHET has also contracted the University of Western Cape to undertake research work on TVET sector for five years, beginning in 2019 (IPSS, 2020). The empirical data collected through this study is expected to complement efforts of such ongoing work. The study hopes to uncover new or unchartered avenues that various stakeholders within the TVET sectoral eco-system can take advantage of, in elevating innovation capability for the country.

The study will also contributes towards the research of sectoral innovation systems in light of the contemporary experiences of 4IR, within a developing economic environment.

1.5. DELIMITATIONS OF THE STUDY

This research will be focusing on TVET colleges and employer-partners, the training methods, tools and technologies they use. While there are other influential role players acting within this sectoral system, such as financial institutions and universities, this research effort does not necessarily focus on those. This was mainly due to the limited resources available and the time frame within which this research had to be concluded.

Non-technological innovations may have a significant role to play on capability building. However, this study is more concerned with (emerging) technological innovations.

1.6. ASSUMPTIONS

It is assumed that there exists a consensus about the importance of innovation capability building for 4IR, by various agents within the TVET sector. Another premise for the study is that its findings will have usefulness for authorities within the TVET sector and scholars interested in the same area of study.

1.7. DEFINITION OF KEY TERMS

The key terms used in this research report are briefly defined in this sub-section. Some of these terms are discussed in more detail in the literature review chapter.

Absorptive Capacity

A capability by firms to recognize, assimilate and apply new knowledge (Cohen & Levinthal, 1990).

Economic Catch-Up

'Reducing of the gap between the forerunning and latecomer economies' (Lee K. , 2019, p. 9).

Industry 4.0. (i4.0) and The Fourth industrial Revolution (4IR)

Both i4.0 and 4IR are terms used interchangeably to describe integration of physical and digital worlds, achieved through exploitation of enabling information and communication technologies (ICT) such as cyber-physical systems and the Internet of Things (GTAI, 2014).

Innovation Capability

The knowledge, skills and other environmental settings required for creation of novel technologies, which include major improvements in design, core product functionalities and production processes (Viotti, 2002).

Learning

The process of technical change achieved by the absorption of already existing techniques, i.e., of innovations engendered elsewhere, and 'the generation of improvements in the vicinity of the acquired innovations' (Viotti, 2002, p. 653).

National Innovation System

The various elements and relationships that interact in production, diffusion and use of new and economically useful knowledge (Lee K. , 2019).

Sectoral Systems of Innovation and Production

'A set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products' (Malerba M. , 2002, p. 250).

Socio-technical systems

Linkages between elements interacting in a specific technology area under a particular institutional infrastructure to generate diffuse and utilize technology; to fulfill societal functions (Geels, 2004).

Knowledge Spillovers

'The external benefits from the creation of knowledge that accrue to parties other than the creator occur at multiple levels of analysis, be it within or across organizations and networks' (Agarwal et al., 2010, p. 271).

Technological Innovations

For this study, technological innovations refer to i4.0 technologies that are relevant to the metal fabrication industry. Access to these technological innovations is expected to enhance 4IR innovation capability building.

Technological Regime

‘The particular combination of technological opportunities, appropriability of innovations, cumulativeness of technical advances and properties of the knowledge base’ (Breschi et al., 2000, p. 388).

1.8. RESEARCH QUESTIONS

The direction of this research will be informed by the main research question.

1.8.1. Main Research Question

How well do components of the TVET system complement each other, towards building the innovation capability necessitated by the Fourth Industrial Revolution?

The main research questions is simplified further by breaking it down to the sub-questions, each directed to one component of the TVET learning cycle, that is: theoretical foundation, practical training, workplace learning, final assessment. The sub-questions are listed below.

The technological innovations that the sub-questions refer to are those industry 4.0 (i4.0) technologies that are relevant to the metal fabrication industry. Access to these technological innovations is expected to enhance 4IR innovation capability building.

1.8.2. Sub-question 1 (RQ1)

To what extent does the theoretical component of the curriculum incorporate sector-aligned technological innovations?

1.8.3. Sub-question 2 (RQ2)

To what extent does the practical training component of the curriculum incorporate sector-aligned technological innovations?

1.8.4. Sub-question 3 (RQ3)

How have the employer-partners (industry firms) incorporated 4IR technologies into their business operations & training programs, to ensure that learners get exposure to practical applications and that they learn by using such technological-innovations?

1.8.5. Sub-question 4 (RQ4)

How does the final assessment component of the program consider the readiness and capability of learners to adapt to the anticipated technological and industrial changes propelled by the 4IR?

1.9. OUTLINE AND STRUCTURE OF THE REPORT

1.9.1. Chapter 1: Introduction

The first chapter is a preamble of the whole study. The section outlines the purpose, context, significance and delimitations of the study. The research problem, underlying assumptions and research questions are also spelled out in this chapter.

1.9.2. Chapter 2: Literature Review

This chapter gives a detailed overview of literature that was reviewed and related to the specific research area of this study. Areas covered include theoretical underpinnings and subject areas that relate to the contextual considerations of the research topic. The research propositions are stated and the conceptual framework presented towards the end of the chapter.

1.9.3. Chapter 3: Research Methodology

In this chapter, the research strategy, design, methodology, selection of participants and data analysis approach used are explained. The chapter also addresses ethical considerations, limitations, reliability and validity of the study.

1.9.4. Chapter 4: Presentation of Results

The data collected during the course of the research are presented in this chapter. The data is simplified and linked back research questions, which were the basis of the questions posed to participants.

1.9.5. Chapter 5: Analysis and Discussion of the Findings

This chapter gives a presentation of analysis performed on research results laid out in Chapter 4. The discussion is coupled with theoretical foundations of the research.

1.9.6. Chapter 6: Conclusions and Recommendations

This is the final chapter of the research. Conclusions and recommendations informed by findings of this research are documented in this chapter.

1.10. CONCLUSION

This introductory chapter has provided a holistic overview of what this research is all about, the guiding structure and what can be expected in the succeeding chapters.

2. Chapter 2: LITERATURE REVIEW

This section firstly expands on the key theoretical concepts informing the direction of this study, which include sectoral innovation system and technological relatedness. Then the focus is shifted towards innovation capability building and emerging technologies. The attention is thereafter given to the TVET sector and 4IR with respect to industry. This approach was used with the purpose to link theoretical frameworks with research questions and the context of the study. The formulated conceptual framework is then presented to conclude this chapter.

2.1. SECTORAL SYSTEM OF INNOVATION (SSI)

2.1.1. Foundations of SSI

The Sectoral System of Innovation (SSI) is the first and main theoretical framework that underpins this research study. According to Radosevic (1998), systems of innovation postulate the technical change to emanate not only from the countries' R&D efforts, but also from inter-organizational learning processes, which are influenced by institutional setups fostering competition and co-ordination. Malerba (2002) elevates the importance of interactions between a set of agents in creation, production and sale of new products intended for particular uses. According to this theory, knowledge, technologies, demand and markets also influence the industrial development within a sector.

Knowledge and learning processes is the first building block for the sectoral innovation systems. Accessibility of both internal (to the firm) and external knowledge can explain level of appropriability of innovations and industry concentration. Knowledge may also be cumulative. This suggests that new knowledge builds on existing knowledge, and that could be through the learning processes and increasing returns at the technology level, organizational capabilities, and market feedback. Accessibility to external knowledge and its transformability to new artifacts may indicate innovation opportunity within a sector. This draws from the work by Breschi, Malerba and Orsenigo (2000) through which they assert that technological and learning regimes vary across different sectors, and that these regimes explain innovation activities within respective sectors.

Basic **technologies** is another building block for SIS. Basic technologies differ by sectoral system, while technology diversification profile among large firms is similar for a given sectoral system. Basic features of knowledge and technology, coupled with demand conditions affect firm's competitive performance characteristics for a sectoral system. Links and complementariness between demand and technologies define sectoral system boundaries.

The third building block relates to structure of **interactions** among firms and non-firms sectoral agents. Firms' heterogeneity is a key consideration for sectoral systems. The sectoral systems differ vastly in agent heterogeneity. Other than firms, which are considered most critical in a sectoral system, there are role payers that support innovation, technology production and diffusion. These include financial, academic, and government organizations among others. Through formal and informal co-operation and interaction, sectoral agents introduce new networks within the sectoral system, potentially integrating complementaries in knowledge, capabilities and specialisation.

The fourth and final building block are processes of **selection** and **variety** generation. This block plays a role on the heterogeneity of sectoral systems. The process can be explained for an example, through different choices that firms and other sectoral institutions make with regard to produced products and developed technologies.

2.1.2. Socio-technical systems as an extension of SSI

Further contributions towards the SIS were made by Geels (2004) in an attempt to address some gaps that he argued existed within the literature. In this work, he puts more focus on dynamics and changes within the sectoral systems, not so much on economic performance and bases his approach on sociology an institutional theories.

Geels (2004) refers to a specific focus the SSI puts on creation of new knowledge. He criticizes the theory for insufficient focus on the diffusion and use of technology. A similar argument is made on how technology transforms societies. Diffusion and use of innovations are an important consideration when studying ways to build new skills and knowledge for the 4IR. This study focusses less on the diffusion process but more on access to innovations that can be used within the TVET sector.

Another gap that he cited was the need to draw a distinction and linkages between the systems and actors that are responsible for sustaining and evolving a sectoral system. The same concern was extended to the importance for proper conceptualization of roles by institutions in dynamic developments. This points to the importance of looking into the interactions that take place within the TVET sector to ensure that critical relationships and roles are well defined in context of sectoral changes that the 4IR may bring about.

Geels (2004) used a multi-level perspective to explain socio-technical changes at three levels, which reinforce each other for transitions to take place. The levels were technological niches, socio-technical regime and landscape developments. The types specific technological innovations that are applicable to the manufacturing sector also form part of this research study. This research takes into account the specific emphasis made by Geels (2004) in his work as complementary to the SIS foundational literature. Subsequently, it is important to closely examine the role of key players within the TVET sector in the process of developing innovation capability. Furthermore, the TVET sector processes should be examined taking into account the dynamics relating the diffusion and utilization of technology.

2.1.3. Learning and catching up in different sectoral systems

Considering that South Africa is a developing economy, it will be useful to reflect on some of the important factorings influencing the learning process within sectoral systems of similar economies.

Malerba and Nelson (2011) use the sectoral systems as a framework to analyze the dynamics of catching up in sectors that are situated in different economic conditions. The key argument that are advanced by authors in this study was that there are notable differences across sectors with respect to catching up. They further recorded some commonalities and differences recorded across sectors. Catching up is considered a learning process, in a sense that the process involves learning by using technology new not to the world, but to the country catching up. The learning process also requires adaptation to indigenous conditions resulting in countries following varying learning pathways. Central to catching up are learning and capabilities by the firms within a respective sector (Kim, 1997), notwithstanding the importance of other agents within an economic sector. In particular, the capabilities required for catching up include access to commentary assets, absorptive capability and innovation capabilities.

Other factors that are important for sectoral innovation systems are vertical links with suppliers and users, universities and public research centers, financial organizations, government and related public policies.

Learning and capability development have been cited as the main determinant for catching up. This is seen as a crucial condition required for support absorption of foreign knowledge and technology; adaption to local demands; generation of new knowledge, technology, products and technologies. Access to foreign expertise from leading firms was one of the reasons for successfully catching up. Development of skilled personnel proved to be even more important for labor-intensive sectors such as computer software and semi-conductors. Direct government intervention in support of various programmes and processes was helpful in advancing catching up across all sectors of focus.

Factors that were unique to different sectoral systems are summarized through the Table 2-1, below. The differences between sectors were explained by the technological regimes that were dominating those sectors, production properties and demand dynamics.

SECTOR	FACTORS INFLUENCING CATCHING UP
Pharmaceuticals	R&D activities by universities IPR Policy Policies support for research
Automobiles	Local and multi-national suppliers
Computer software and services	Focus on training and access to skilled personnel Funding institutions - VC
Telecommunication equipment	Policies support for research PROs
Semiconductors	Policies support for research
Agricultural-food	Agricultural research organizations Market institutions

TABLE 2-1 FACTORS UNIQUE TO EACH SECTOR

The study also revealed that sectors performed differently to other sectors within the same country for the period studied, reaffirming that certain sectors can perform better in catching up when compared to others. In an effort to explain this phenomenon, the authors attribute this to an interplay between the national innovation system and sector-specific factors within a country. Initial sectoral conditions and national innovation system for a specific country have a lot to do with catching up performance. The needs for sectoral systems are also not the same. For an example, while firm size may be important for one sector, strong university system may be more important for another.

2.1.4. Sectoral Innovation Systems in the era of 4IR

Locating the sectoral innovation systems within the context of fourth industrial revolution, Li et al. (2021) look at possible changes that the fourth industrial revolution might introduce to sectoral innovation systems. I4.0 was first introduced in 2011 as made possible by technologies that enable integration of physical and virtual worlds, facilitating wider interaction and communication among objects (GTAI, 2014). Examples of enabling technologies include but are not limited to cyber-physical systems (CPS), internet of things (IoT), and industrial information integration. I4.0 was symbolized the beginning of the fourth industrial revolution (Xu, Xu, & Li, 2018) , a term later made more popular by the World Economic Forum later when they extended i4.0 by also emphasizing economic and societal transitions (Schwab, 2017; Li, Liang, Tell, & Xue, 2021).

An overview of all four industrial revolutions are summarized through figure 2-1 below.

The Age of Steam	1ST INDUSTRIAL REVOLUTION Introduction of mechanical manufacturing systems utilizing water and steam
The Age of electricity	2ND INDUSTRIAL REVOLUTION Introduction of mass production utilizing electrical power
The Information Age	3RD INDUSTRIAL REVOLUTION Introduction of electronic and ICT systems for automation
The Age of Cyber-Physical Systems	4TH INDUSTRIAL REVOLUTION Officially presented for the first time in 2011 (GTAI 2014)

Figure 2-1 An overview of industrial revolutions [Source: (Xu et al., 2018)]

Due to ICT's ability to penetrate through various sectors, we are seeing more collaboration of unrelated sectors such as automobiles and ICT resulting in blurring of boundary lines Li et al. (2021). Changing customer preferences and new technological possibilities are some main drivers behind the rapid changes on the demand side. There are now more possibilities for firms to offer customized and differentiated products to users. On the policy side, governments are faced a challenge to re-evaluate provisions with regard to data governance, security, governance and other socio-economic considerations such as unemployment. There is a noticeable increase in competition due to entry of new firms leveraging 4IR related technologies. In some cases, this has resulted in some authorities flexing their muscles and shutting down operation of these new technology firms within their regions. On the other hand, more collaboration that promotes technological convergence results in expansion of boundaries at both firm and sectoral level (Fu, Fu, C., Romero, & Pan, 2020).

After a comparison between 3IR and 4IR, a recent study by J. Lee & K. Lee (2021) concludes that 4IR is associated with technological changes that both evolutionary and path-dependent, and not radical changes as it were the case with 3IR.

2.2. TECHNOLOGICAL RELATEDNESS

The second and complementary theoretical concept that provided guidance for this research is Technological Relatedness, within the context of learning.

Chatzistamoulou et al. (2022) presented the concept of learning taking place through the effect of spillovers from the productive perfomance. In this context, the spillover effects occur autonomounsly but moderated by absorptive capacity, whose proxies are the country’s capabilities, competencies, and accumulated knowledge. The transfer of knowledge by way of spillover effects can also take place within the TVET sector being studied by this research. Similarly, the capabilities, competencies and accumulated knowledge can be used to evaluate their effect on knowledge spillovers.

Frontiers of technologies can be characterized by differentiated level of technological complexity, relatedness and variety. They differ between industry specific frontiers and country specific frontiers. Those at higher aggregation level are defined by high technological variety, more complexity and distance (between different technologies). At lower aggregation, the technologies are less complex and more related.

Using the scope of this study to elaborate on this point, the level of technological complexity can be expected to be relatively higher at the manufacturing sector level when compared to sub-sector level. This would subsequently imply that the level of technological relatedness is lower within the sector. Technological relatedness has an inverse association with complexity and variety. Within the same manufacturing sector, an example of a lower aggregation level can be the industry such as metal fabrication. At this level, the types of technologies used by different firms could be different but closely related.

The country-specific industry structure (CSIS) is constituted by industry-specific frontier (Castellacci, 2007) and country-specific production frontier (Bartelsman et al., 2013). This relationship explains the link that exists the lower and higher aggregation levels. Put differently, arrangements and activities that take place at the sector level can be expected to have an impact at a macro-economic level.

A learning grid is an area between different knowledge pools where the transfer on knowledge occurs. For this study that can refer to the a space encompassing both the metal fabrication industry and the colleges that are directly linked to the same industry. At an aggregated level this could be mean a space where other industries (more and above the metal fabrication) and all colleges that specialize on various trades, but all that fall within the manufacturing sector.

Spillovers are understood to be impactful to CSIS's productive performance when they originate from related technology learning (sector-specific technologies), but are idiosyncratic to industry, sector and country. Studying technological relatedness at a sector level is important to understand the potential impact of sectoral activities on innovation capability building at CSIS level.

Within the context of a region, technological relatedness has been found to be fundamental in creation of new industries (Boschma & Frenken, 2010). The interaction and co-operation of firms and individuals need to have related shared competencies to create new knowledge and innovations. Relatedness also plays are moderating role for occurrence of knowledge spillovers in a region. Too much homogeneity is however, disadvantageous for transfer of knowledge to take place, as there may be too little to learn. Instead, related variety is preferred for facilitation of learning.

Path dependence is influential to production performance of both complex and related frontiers due to institutional, cultural, and initial CSIS conditions. It is therefore important to understand that adaptation will form an important part in 4IR capability building.

In another study, Hu (2021) investigates how the spillovers related to imports, and foreign direct investments (FDI) influence technological progress of BRICS member countries. He also interrogated the link between human capital and the spillover effects. The findings suggest that the increase in the country's economic output, human capital, R&D expenditure, and FDI-related externalities have a favorable effect on technological advancement, in BRICS nations. The study also finds that human capital development plays a moderating role on innovation that is explained by imports; it also improves the potential for absorption of advanced technologies. By extension, the total factor of productivity can also be expected to improve as a result of innovation capability building.

2.3. INNOVATION CAPABILITY BUILDING IN DEVELOPING ECONOMIES

The definitions of innovation capability vary among a number of scholars. Viotti (2002) defines innovation capability as the knowledge, skills and other environmental settings required for creation of novel technologies, which include major improvements in design, core product functionalities and production processes. Innovation capability is characterized by capacity to transform external knowledge to new products and processes (Urgal et al., 2011) and successfully introduce them to markets (Tang et al., 2020; Hurtado-Palominoa et al., 2022).

Drawing from the work by Lee (2019) on economic catch-up, latecomer countries have different economic growth mechanisms when compared with developed countries. Developed countries have in-house research and development capabilities while low and middle-income countries have to seek alternatives means for building innovation capabilities to transition to high-income stage (Lee, 2019). To cultivate innovation capabilities, latecomer firms need to be provided with a learning opportunity (Lee, 2019). Firm level capability building also involves sectoral and national innovation systems within which the firms are located. The elements required for innovation capability building include designing a working innovation system made up of agents responsible for innovation and production, presence of institutional settings, and the links between the innovation system actors. Lee (2019) speaks of three detours that can help latecomer economies build their innovation capabilities. These are briefly outlined below.

i. From imitation to innovation

Intellectual property rights (IPR) protection can be hindrance to innovation for latecomer countries. For an example, use of patented technologies maybe be limited to only high income countries responsible for developing them, while low-income countries lack capabilities to invent their own.

Promoting petit patents instead of regular patents

Utility models (petite patents) are one option that latecomer countries can consider over patents at early stages. This type of patenting involves licensing of minor invention for shorter patent periods, at more affordable costs and usually excludes methods of production. An example of a country that extensively used utility models is Korea. This was at the time when the country depended a lot on foreign technologies. They would learn and adapt these technologies. Thereafter, they would use the utility models to register improvements developed domestically.

Promoting trademarks instead of regular patents

Trademarks are another alternative that encourage firms to produce high quality products. Unlike utility models, trademarks are more domestic-market-focused and closely tied to the brand strategy. They can be useful in cases where the invention is based on tacit sectoral knowledge and when firms do not possess capabilities to introduce complex patentable inventions. Korea can once again be cited an example of a country that registered more trademarks than patents before the year 1980.

ii. Short and Long-cycle technologies

Specialisation in labour intensive sectors at initial stages is recommended for economies with abundance of labour as existing market structures support labour intensive sectors even when the technological knowhow lags behind. When middle-income countries have developed high levels capabilities, they start targeting high value sectors thereby competing with some of the frontier economies with an advantage of scale and experience.

Targeting and specializing in sectors characterized by short-cycle time technologies gives latecomers a low entry and quick growth advantage over incumbent sectors who tend to cling onto the long-cycle technology sectors they have strong holds over. With short-cycle time technologies, existing stock of knowledge is less useful and new knowledge becomes obsolete quicker.

Modularization of technological regime gives latecomers an opportunity to outsource some of the technology components to specialist suppliers, by so doing, latecomers can focus on developing only specific knowledge for insourced components, reducing the learning duration. Codified knowledge also increases learning speed compared to tacit knowledge, which is more difficult and slow to learn.

In short, at a particular point when the latecomer has achieved catching up, that is the time to specialize in long-cycle technologies.

iii. Domestic and Global Value Chains

Late comers can initially participate in global value chains (GVC). However, there should be a specific focus towards building local knowledge base. After acquisition of knowledge, the latecomer should steer away from GVC and participate on domestic value chains.

2.3.1. Building absorptive capacity

Innovation capabilities by themselves are not sufficient for guaranteed corporate innovative performance (Lyu, Peng, Yang, Li, & Gu, 2022). Malerba and Nelson (2012) also insist that countries require access to complementary assets, innovation capabilities and absorptive capabilities to successfully catch-up with leading economies. Cohen & Levinthal (1990) defined absorptive capacity as a capability by firms to recognize, assimilate and apply new knowledge. It is dependent on related prior knowledge and is critically important for the firm's innovation capabilities. The presence of prior knowledge makes it possible for firms to both assimilate and exploit new knowledge. Developing absorptive capacity enables accumulation of new knowledge, and expertise for assessing related new technologies. Accumulation of absorptive capacity may also present a negative case if at some point the firm stops investing in building absorptive capabilities, allowing path-dependence effects to lock the organization out from exploitation new opportunities.

Hurtado-Palominoa et al. (2022) studied the innovation capability, and the acquisition and assimilation of new knowledge (potential absorptive capacity) with respect to innovation performance within the cultural tourism sector in Peru. The results confirm that both variables studied are antecedents of innovation performance and that both variables have a reciprocal effect on innovation performance. This reaffirms the importance of acquiring external knowledge and use of such knowledge to generate and transform new ideas to new products and processes.

2.4. EMERGING TECHNOLOGIES IN EDUCATION SECTOR

The development of online libraries and forums has facilitated interaction of students, teachers and researchers among each other irrespective of their locations. This has supported various discussions by specialists relating to curriculums, teaching pedagogy, and assessment methods (Haleem, Javaid, Qadri, & Suman, 2022). Hybrid teaching and learning offer blended use of offline and online teaching and learning. Technological capabilities have also supported distance-learning education, providing easy and convenient access to learning. Technologies that are focused on difficulties related to speech, hearing and reading, help facilitate teaching of students with various special needs.

Virtual classrooms, augmented reality, robots are some of the technologies that have a capability to create an inclusive, exciting and collaborative learning environment for learners of different learning abilities, while enhancing monitoring and capturing of learner performance. Highly participatory modes such as video-based instructional learning have also been a prevalent style of teaching.

Other discussions on emerging technologies in education include the importance of perceptions by instructional opinion leaders and teachers (Ngoc, Hoang, & Hung, 2020). Among other findings, Ngoc et al. (2020) highlighted the importance of empowering educators on incorporation of emerging technologies into teaching programs when transforming education.

Meirbekov et al. (2022) make a case for the effect of using some emerging technologies in developing critical thinking. The results of the study, which was conducted as an experiment on university students using two digital technologies that were deemed relevant for the study, were consistent with the positive effect digital tools has on development of critical thinking.

Li et al. (2022) undertake a systematic review of extant literature on the effect of emerging technologies in promotion of creativity within the education environment. Even though concerns are were raised regarding inconsistent detail and reporting format on implementation of the technologies, one of the findings suggests that various types of technologies influence different aspects of creativity. Wearable virtual reality trigger student's creative behaviors (Yang, et al., 2018); visual thinking tools stimulate visualization of conceptual ideas (Simper, Reeve, & Kirby, 2016), and multimedia production software unlocks student's ability to conceptualize ideas (Cantero, 2017), while web-based technologies broadens the lens through which students view situations they are confronted with (Stolaki & Economides, 2018).

2.5. 4IR, MANUFACTURING AND SOUTH AFRICAN INDUSTRIES

The implications of 4IR primarily include product improvements, organizational modifications, change in expectations by customers and collaborative innovation (Serumaga-Zake & van der Poll, 2021). The technological drivers for 4IR are can be categorized as physical, digital and biotechnological (Fanoro, Bozanic, & Sinha, 2021). The application fields for each category are shown on the table that follows.

TECHNOLOGICAL DRIVER	APPLICATION FIELD EXAMPLES
Physical	3D printing Collaborative robots
Digital	Industrial internet of things Artificial Intelligence
Biotechnological	Neurotechnology

TABLE 2-2 4IR INDUSTRY FIELD APPLICATION EXAMPLES [SOURCE: FARONO ET AL., 2021)]

2.5.1. In manufacturing industry

This study specifically focuses on colleges that specialise with the welding and boilermaker trades. These two trades are part of metal fabrication, which is a sub-set of the manufacturing industry. Virtual reality, Internet of things, industrial internet of things, 3D printing and artificial intelligence are some of the technologies that have reshaped manufacturing one way or the other. Manufacturing has also been categorized as traditional, intelligent, flexible, reconfigurable, cloud-based and IoT-based smart manufacturing (Fanoro, Bozanic, & Sinha, 2021).

Smart manufacturing may involve use of robots with computer vision and sensors to automate various manufacturing activities. IoT-enabled manufacturing is associated with real-time collection and transfer of data between related jobs, workers and machines. Data is made available at multiple layers (from machine to system level), supporting data-driven decision making. Cloud-based manufacturing can be implemented for manufacturing that is supported by intelligent computing, IoT, and virtual reality. Advanced, decentralized technologies within a network provide computing and service oriented frameworks. The resources required include cloud and local servers, and physical equipment.

Traditional manufacturing is human intervention intensive and process components are decoupled, not linked by any form of communication system. The process is rigid and difficult to adjust or reconfigure in cases of demand changes. This type of manufacturing is associated with high maintenance costs and lower levels of productivity.

Flexible manufacturing involves possibility easy modifications or adjustments in case of process changes. The key advantage for using this technology is the flexibility that is made possible when operating machines and robots. Intelligent sensors also add a possibility of self-optimization by enabling the process to run continuously.

Reconfigurable manufacturing systems are characterized by scalability, customizability, integrability, modularity and diagnosability. The technology makes it possible to change machines as the throughput requirement change, incorporating benefits of both dedicated manufacturing lines and flexible manufacturing systems.

Integration of various systems is also another approach that can be considered by innovative organizations when implementing i4.0 technologies to strengthen the intelligence of manufacturing processes. The integration can be horizontal, the automated coalescence of ICT systems across firms which may be offering similar services. It can also be applied vertically by incorporation of IoT, AI, cloud computing and big data to information and automation technologies along the value chain after acquisition of other companies. Another integration approach is end-to-end digital integration. This approach involves identifications of customer value and value stream mapping that can be used to develop customized and automated products and services.

2.5.2. Readiness by South African industries

Maisiri & van Dyk (2019) assessed the readiness of South African organizations for i4.0. The proposed categories and related set of indicators for carrying out such an assessment are shown in table 2-3 below.

CATEGORY	SUB-CATEGORY	INDICATOR
Organizational strategy	Implementation of i4.0 strategy	Progress of implementation Alignment with the main organizational strategy
	Investments	Identifiable areas where plans or actual i4.0 related investments have been made
	System-based approach in management of technology and innovation	Identifiable cased of where this approach is used
	I4.0 technologies	A quantity of such technologies being utilized
Organizational infrastructure	Capabilities of equipment being used	Level of IT incorporation Utilization of Machine-to-Machine (M2M) digital interfacing and Inter-operability
	Adaptability of machine capabilities	Utilization of M2M digital interfacing Inter-operability
	Digital modelling	Data acquisition and processing
	Systems and their integration	Systems in use Systems integrated with leading interface
Smart operations	interdepartmental information flow	Established interdepartmental information communication systems
	Autonomous functionality	Real-time autonomous process response and guides
	IT solutions	Organization Security measures in place

		Cloud-based systems utilization
Smart products	ICT-based capabilities	Add-on features
Data-driven services	Data processing	New services resulting from data processing
Staff personnel	I4.0 skills	Skills complement

TABLE 2-3 I4.0 INDICATORS [SOURCE: MAISIRI & VAN DYK (2019)]

Industries studied included manufacturing, mining, chemical, aerospace and others. Small, medium, and large enterprises constituted 14%, 25%, and 61% of the studied sample respectively.

In terms of overall readiness, the study results indicated that 11% proportion of organizations had not done and were not intending on doing anything about i4.0 while 34% was at the beginning stages. These organizations fell under the emerging level category. With regard to organizational strategy, 47% were emerging (either had no strategy in place or there has only been a pilot), suggesting lack of commitment towards i4.0; and 33% was developing.

In terms of organizational infrastructure, 42% or organizations were classified as emerging and another 42% as developing. This suggests that a significant proportion of organizations could be lacking equipment infrastructure or equipment used by these organizations may not be upgradable for i4.0. A similar picture was noted with regard to smart operations with emerging and developing categories accounting for 78% of the organizations.

A separate study focuses on i4.0 technologies used by Germany, China and South Africa within the energy sector (Bhagwan & Evans, 2022). South Africa came out as a worst performer with regard to number of publications, highlighting a concerning gap on research related to i4.0 technologies for the energy sector.

2.5.3. 4IR adoption by South African industries

In another study focusing on automotive and mining equipment manufacturers, and related services, Lorenz et al. (2019) investigated the use of i4.0 technologies by the South African industry. The automotive sector is highly automated and with factories heavily relying on industrial robots for their operations. The sector is also closely tied with the few multi-national companies who largely take over the control of product and process innovations.

The mining equipment sector on the other hand has low levels of automation owing to its high product customization and limited batch sizes. Mining equipment producers, who are mostly local companies, have strong product innovation capabilities that are explained by strong user-producer relationships that facilitate knowledge spillovers within the sector.

The research outcomes also point out to the existing gap between the skills of TVET graduates and those that are required by industrial enterprises in practical work settings. Low data analytics skills and poor connectivity add to the challenges experienced by the mining companies. Another gap concerns the differing levels of technological capabilities between automotive OEM's and suppliers. A number of business service providers were reported to have strong capabilities with regard to data analytics and use of sensors for automation. However, low skill levels and understanding of potential benefits related to such capabilities by potential end users, have been cited as constraints suppressing the demand for the 4IR related technologies.

2.6. THE TVET SYSTEM IN SOUTH AFRICA

2.6.1. Overview

The TVET system is part of a broader PSET system alongside Community Education and Training (CET) colleges, universities, and private education and training institutions/institutes. The system falls under the competence and responsibility of the DHET, and feeds from the upstream components of the education system such as early childhood development, primary and secondary education. Institutions that form part of the TVET system support structure include skills levy organizations, qualifications and quality assurance bodies, and other organizations such as approved workplaces (for work-place-based learning), professional bodies, and trade test centres. The primary purpose of TVET colleges is preparing learners for the workplace and self-employment (DHET, 2013). There are currently 50 registered colleges forming part of the TVET system (DHET, 2021).

2.6.2. Sector-focused research

The White Paper on Post-school Education and Training (2013), which was a blueprint for policy direction with regard to PSET, has been foundational to some of the recent research work focusing on the sector. The paper largely consulted other policy documents such as the National Development Plan (National Planning Commision, 2012), the New Growth Path Framework (Economic Development Department, 2010), and the Industrial Policy Action Plan (DTI, 2017). With regard to TVET colleges, The White Paper elevated strengthening and expansion of TVET colleges as the DHET's highest priority. The key objectives included improvements in management and governance, development of quality with respect to learning and teaching, increasing responsiveness of colleges to labour markets, improvement of student support, and development of infrastructure. Collaboration with industry employers is seen as key for facilitation of work-integrated learning and placement opportunities for learners upon qualification.

One of the key projects currently going on is the DHET-NSF research programme on TVET, aimed at enhancing knowledge and understanding that can be used when implementing interventions towards continuous improvement on TVET colleges, by building significant and local body of knowledge (IPSS, 2020). The study is a collaboration between DHET, National Skills Fund (NSF), and University of Western Cape Institute for Post-School Studies (IPPS). The main objectives for the research include improving information on TVET College system; establishing sustainable research processes; linking research to policy and practice; and capacity building.

2.6.3. Innovation and TVET colleges in South Africa

NACI was recently mandated by the minister of Higher Education, Science and Innovation to investigate the state of innovation within TVET sector (NACI, 2021). In this exploratory study, NACI conducted literature review, online surveys with college principals, and interviews on various stakeholders linked to colleges.

The findings highlighted college governance as one of the main constraints to innovation at TVET colleges. Interactions and collaborations between TVET colleges with other stakeholders are reported to have been weakened by trust breakdown with respect to college capacity and willingness to have meaningful engagements. Process innovation was reported as more dominant compared to the rare cases of product innovations at colleges.

Due to the critical role that the TVET system in developing the South African economy, the report recommends conceptualization and integration of the sector into the National System of Innovation (NSI). Further, the report advocates for transformation of the TVET sector amidst rapidly evolving economic and work conditions, and makes recommendation in this regard.

There needs to be a renewal of the policy, governance and leadership environment to address constrains and ineffectiveness caused by current policies to TVET college's innovative practice. An example is the top-down governance, which tends to exclude participation of colleges when certain interventions are introduced to the system, leads to low responsiveness to labour market demands. The representativeness of local entities and industries by industry partners was also questioned. Another recommendation made was for colleges to engage more with innovators and for assistance to be provided so they can better understand the complexities involved with the NSI. Colleges also need more autonomy and freedom for experimentation with their peers to promote an innovative culture.

Development of a functional competence is required for TVET colleges to effectively contribute towards innovative activities within the NSI. Centres of Specialisation are a possible means for consolidating links between colleges and other innovation system actors. The final recommendation was about the necessity to implement a centralized monitoring and evaluation, and measurement system, which is an imperative for policy learning, efficiency and effectiveness.

2.6.4. Centres of Specialisation (CoS) programme

In 2019, the DHET launched a pilot project for the Centres of Specialisation programme, as part of government's Strategic Integrated Projects (Jet Education Services, 2021). The formulation of SIP was as a result of the government's planned infrastructure investment programme in 2012. Projects that could be classified as SIP were those that would have significant social or economic significance for the country; or contribute towards a national strategy or policy relating to infrastructure development (The Presidency, 2014). The Presidential Infrastructure Coordinating Commission Council (2022) published the latest of list of SIP in 2022. Skills required for these projects to succeed were then investigated and the top thirteen of the skills identified were prioritized. The Centres of Specialisation program was established for developing these priority skills.

Welding and boilermaking are among the priority trades for which the DHET setup structures to develop (DHET, 2016). Other trades include rigging, bricklaying, plumbing, mechanic, millwright, electrician, diesel mechanic, carpentry and joining, fitting (pipe and mechanical) and turning. The number of CoS's is 34 from 20 different TVET colleges, and the first cohort of the 3 year programme graduated in November 2022 (DHET, 2022).

The programme is about college differentiation, promotion of quality teaching and learning, facilitation of responsiveness, modeling the implementation of QCTO's trade qualifications, while developing artisanal skills required for economic growth. It is based on a dual system model, which involves collaboration between colleges and industry employer-partners. Selected colleges are assigned and equipped for one or two of the thirteen priority trades. The two main objectives are, to address priority skills demand and capacitation of public TVET colleges for delivery of trade qualifications.

2.6.5. Other innovation focused initiatives

The Imbali Education and Innovation Precinct is still at a set-up stage with some of the project team members being recently appointed; recommendations of steering committee members and terms of reference still to be finalized. The details about how the precinct will operate are very limited at this stage, but the project is meant to explore education delivery alternatives through integration of educational institutions and the national innovation system.

The Chemical Industries Education and Training Authority (CHIETA) through the Smart Skills Centres is working towards bridging the digital gap between rural and urban communities (CHIETA, 2022). The project is said to provide disadvantaged communities with access to internet, digital skills and capabilities. So far, only the one center has been launched, but the project intends to roll out these centres countrywide. Another pilot project that is aimed at digitization of technical skills at TVET colleges, that CHIETA has implemented, is the Coded-Welding E-learning with TVET. This project is also aimed at developing unemployed youth.

Another initiative by the DHET is establishment of 4IR Centres of Excellence in selected TVET colleges (DHET, 2021). The details about this project are also limited at this point, but it is understood that selected colleges will establish 4IR mini-laboratories in collaboration with relevant industries to roll out related programmes.

2.7. HIGHER EDUCATION AND TRAINING IN SOUTH AFRICA

The Republic of South Africa has amalgamated the DHET and The Department of Science and Innovation (DSI) into one ministry (Parliament of RSA, 2023). The two departments are collaborating closely (with other departments, international partners and industry) in development of human capabilities. This nexus is also expected to expand the science base of the National System of Innovation and developing an innovation mindset from an early age.

DHET has a specific focus towards the National Development Plan's priority three (which is about education, skills and health), while supporting the implementation of priority two (transformation of the economy and creation of employment) (DHET, 2022). For priority three, the focus is on improving quality, accessibility to PSET opportunities, and the responsiveness of PSET system. The PSET system is made up of public university, TVET, and CET sectors.

The DSI also has its focus on both priority 2 and 3 of the NDP (The Portfolio Committee on Higher Education Science and Innovation, 2022). The desired outcome for priority 2 was also stated as improvement of competitiveness through adoption of Information and Communication Technologies. The TVET sector, which is a primary focus of this study, has a significant role to play in developing capabilities that are aligned with the broader national agenda. The CoS program is one of the strategic initiatives that can be used to realize some of these objectives.

Along with several other recommendations, The White Paper on science, technology and innovation (DST, 2019) had emphasized the importance of thinking in socio-technical systems, exploiting the role of ICT, and expansion of STI human capabilities when developing policy responses. This further strengthens the argument on why the sectoral system of innovation is the appropriate approach to use when studying innovation capability building for 4IR.

2.8. CONCEPTUAL FRAMEWORK

Figure 1 depicts the conceptual framework emerged, informed by interceptions of the Sectoral Systems of Innovation, and the Technological Relatedness concepts. The framework positions the Centres of Specialisation (TVET colleges specializing in specific trades) first, as part of related technology learning grid, and secondly, as part of a broader TVET Sectoral Innovation

System. The (emerging) technological innovations which are consistent with industry trends, are embedded in all components of the CoS learning cycle. Interaction between sectoral agents and movement of human capital within this conceptual structure will facilitate the natural occurrence of knowledge, skills and expertise spillovers, enhancing innovation capability building for industrial and technological development at country level. The spillovers are multidirectional, flowing between sectoral agents, from meso-level to macro-level, and macro-level to meso-level.

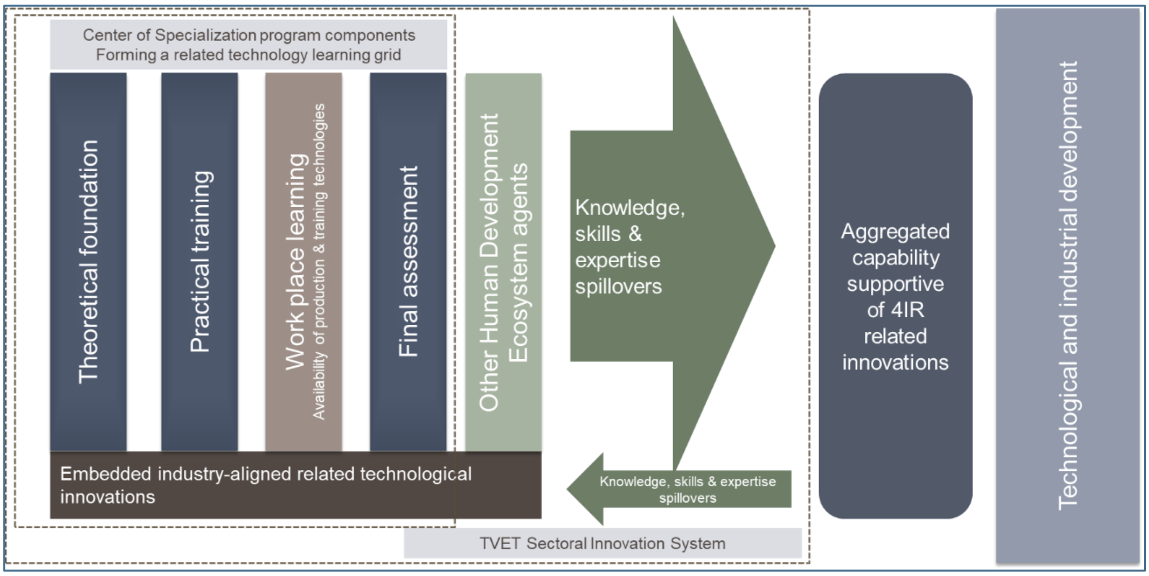

FIGURE 2-2 DIAGRAMMATIC REPRESENTATION OF THE CONCEPTUAL FRAMEWORK [SOURCE: AUTHOR]

2.9. SUMMARY

This literature review confirms the evidence of extensive work that scholars have done within the sectoral innovation systems research area. Part of the literature was useful in locating this discussion within the context of developing economies. The literature on technological relatedness, absorptive capacity and learning processes adds complementary understanding on how knowledge transfer can be realized within a sectoral system. The literature relating to higher education and more specifically the TVET sector suggests that the policy positions and focus areas are informed by research that can be traced back to the dawn of democracy days.

Even though the concept of 4IR is not that new anymore, there is shortage of academic literature relating to the development and diffusion of emerging technologies within the local industry. The same comment can be made for the metal fabrication industry, which is a subsector within manufacturing. Similarly, some of the grey literature reviewed suggests that there is a specific effort directed at empowering the TVET sector for requirements of 4IR. However, there is limited availability of literature outlining the state of sector with respect to this topic, and the coordination of various initiatives for focused capability building.

This study did not seek to establish the type of technological regime that may prevail in South African industries, however the point should be made that the technological learning will be moderated by technological conditions that dominate firms and sectors in South Africa. Studies focusing on technological regimes within the South African context can help explain country's technological trajectory, more specifically around the discussion about 4IR.

The recent education sector-focused research papers reviewed seem to have put specific attention on the colleges and not so much the industry even though South Africa through DHET, has embraced the workplace centered dual-system approach for the TVET sector. Innovation System focused research on the other hand tends to focus more on the role of universities and R&D capabilities rather than other capabilities required by downstream stages of the innovation process, like those that can be developed by the TVET sector for the innovation system to be fully functional. This research interrogates the state and the potential of both colleges and industry partners in developing learners for the changing workplace. It shifts the focus a little away from the R&D research capabilities (notwithstanding their importance) to other forms of learning that developing countries like South Africa can leverage.

The conceptual framework introduced above provides links among different aspects that were discussed in preceding sections, clearly visualising the frame of this enquiry.

3. Chapter 3: RESEARCH STRATEGY AND METHODOLOGY

3.1. INTRODUCTION

Since this research study was interested in establishing contemporary facts unique to the TVET sector in South Africa, interpretivist approach was adopted for this research. The logic behind this choice is supported by Myers (1997) who asserts that interpretivism is offers great value when persuing contextual depth.

3.2. RESEARCH STRATEGY AND DESIGN

The report seeks to deepen understanding configuration of the TVET sector with respect of sectoral innovation system, and capability building for the 4IR. According to Yin (2003), the case study gives generic understanding about the studied case. This is realized by investigating the process or practice, the interactions within the process and the meaning of the interactions. The case study research method was thus selected as the most fitting choice for this study. A qualitative approach was also selected as a methodology for this study. Even though the research results obtained through this approach are not generalizable, more in-depth understanding of the studied context can be achieved.

Two cases were used for this research study. Each case represents a specific priority skill. One case represented boilermaking and the other represented welding. For each case the sub-units of analysis included the college and the employer-partner that collaborates with the college for the CoS program. The two cases that were selected for this study are trades that form part of the metal fabrication industry. It was therefore envisaged that each case would make a meaningful contribution towards the overall understanding of the studied sample in terms of both the defined sectoral system of innovation and technological relatedness.

There was no apparent reason to anticipate resistance from participants that would be approached for interviews, since the topic of the research was not expected to introduce any form of threat or intimidation. DHET also views research work in a positive light hence they have an official policy that guides research related activities in TVET colleges. The plan was to conduct most interviews through virtual conferencing platforms such as Zoom, once confirmed.

3.3. SELECTION OF STUDY SAMPLE

According to the DHET's 2021/2022 annual report (DHET, 2022), there are currently 34 established Centres of Specialisation across the country. These CoS's have been mandated and capacitated to develop the top 13 critical trades (DHET, 2016).

Two cases were used for this research, one focusing of welding and the two in the boilermaking trade. Welding and boilermaking are related in terms of industry application of the trades, with both trades lending themselves as part of critical occupations needed by the metal fabrication industry. Multiple-case studies produce more credible research outcomes than single cases studies (Yin R. K., 2013). This combination of these cases enhanced the quality of the research in a sense that the two cases complement each other in light of the technological relatedness concept due to the industry they both serve, the metal fabrication industry; and the overlapping scope of activities that exists between the two trades. Both cases also form part of the manufacturing sector, which is one of the sectors that I4.0 technologies are expected to have most impact on. These two cases also offer an excellent opportunity for studying sectors where traditionally, digital technologies were not foundational. While the selected cases are not necessarily expected to be involved with upstream activities of the 4IR value chain, a number of innovations are intended for environments represented by both these cases.

Industry employer-partners were interviewed to understand the type of technology they have access to, and how they have been supporting the CoS program with respect to research sub-question RQ3. College representatives were interviewed with the aim to understand practices, methods, technological innovations they use, and to sense a level of orientation towards 4IR capability building, with respect to research sub-question RQ1 & RQ2. Trade assessment centres were looked at with the aim of investigating details of the assessment process with respect to research sub-question RQ4. Students that were considerably close to completing the program were interviewed to understand how the program might have prepared them for 4IR.

More and above the main and sub-units, industry associations and leaders of specific projects by other organizations were contacted to extract additional insights related the research questions in cases where their input was expected to assist the research.

3.3.1. Background Profile of Respondents and Process Followed

Since the public TVET colleges form part of DHET, the approval for conducting research was only granted after the requirements prescribed by DHET's policy (2016) were fulfilled. See Appendix F. Four colleges were approached for conducting this study (two specializing in welding, and two others specializing in boilermaking occupations). Each of the four colleges approached were requested to assign two employees to participate in the interview process; one participant at level of overall CoS project management, and the facilitator responsible for the specific trade i.e. boilermaking or welder. The colleges were also asked to assign two students that either had completed the program or were about to complete. Since partnerships that are in place between the respective colleges and the employer-partners are not publicly available, colleges were best placed to share the names and contact details for respective partners. As a result, acquisition of this information mainly depended on the cooperation by the colleges. Once this information was made available, requests to conduct research interviews were made to individual employer-partners through contact details provided.

One of the colleges declined the invitation to participate. The reason given was that the college did not think that they were in a suitable position to participate, since the college was intending embarking on 4IR related programs in 2024. This unfortunately meant that it would not be possible to contact employer-partners working with this college as well thus shrinking the size of the sample.

The colleges that agreed to participate generally engaged positively and openly. However, some of the industry partner representatives declined to participate while efforts to contact some students were unsuccessful. Only CoS2 and CoS3 college representatives were interviewed through face-to-face discussions, the rest of the interactions were either virtual, telephonic or written responses. In an effort to maintain anonymity of the colleges and associated employer-partners that participated in this study, the Centres of Specialisation will be referred to as CoS1, CoS2 and CoS3 henceforth.

Each research question could be partially answered through review of the grey literature. In the quest to obtaining the latest operational documents used by the CoS program, the DHET was approached initially by telephone. A senior official from the department suggested a meeting and offered to share their expertise through discussing the background to the CoS program, giving advice on where and how to obtain some of the requested information. The meeting proved to be quite informative and provided useful insights about reliable public platforms that can be used to access the information. Relevant officials thereafter shared other pieces of information that could only be obtained through DHET via email. Written responses to specific questions were also requested from a SETA and industry association organization representatives. The profile of the research sample and the nature of interactions are depicted by the table 4 below.

Organization Type	**Respondent's Role Profile**	**Engagement Type**	**Count**
Government Department	Director	Unstructured interview	1
CoS - College	Project Manager	Semi-structured interview	3
CoS - College	Facilitator	Semi-structured interview	3
CoS - College	Student	Semi-structured interview	3
CoS - College	Deputy Principal	Unstructured interview	1
CoS - College	H.O.D	Unstructured interview	1

CoS - Employer-partner	Director	Semi-structured interview	1
CoS - Employer-partner	Manager	Semi-structured interview	1
CoS - Employer-partner	Foreman	Semi-structured interview	1
Industry Association	Senior Official	Unstructured Interview	1
Industry Association	Senior Official	Written response	1
SETA	Manager	Semi-structured interview	1
Total sample size			18

TABLE 3-1 SAMPLE CHARACTERIZATION

The table above depicts the decent sample size for the conditions under which the study was conducted, and some degree of triangulation in terms sources used for data collection.

3.3.2. Employer-partners

Only two out of five employer-partners agreed to participate in the interview process. The industry segments within which each of the companies operate are profiled on table 8 below.

<table>
<tr><th></th><th>Employer-partner 1</th><th>Employer-partner 2</th></tr>
<tr><td>CoS1</td><td>Large transportation products (road)
Interviewed</td><td>Large transportation products (road)
Not-interviewed</td></tr>
<tr><td>CoS2</td><td rowspan="2">Various forms of steel
Interviewed</td><td>Structural metal fabrications
Not-interviewed</td></tr>
<tr><td>CoS3</td><td>Earth-moving equipment
Not-interviewed</td></tr>
</table>

TABLE 3-2 INDUSTRY SEGMENTS FOR EMPLOYER-PARTNERS

3.4. RESEARCH METHODOLOGY

The qualitative research methodology was found to be the most relevant for exploring the ‘how’ question about the TVET sector with respect to 4IR innovation capability building. This approach is consistent with interpretivism stance, reveals nature of a specific setting, and helps provide means of judging the effectiveness of particular innovations (Peshkin, 1993). The research pursued knowledge through acquisition of qualitative data (Kaplan & Maxwell, 1994).

3.4.1. Data Collection and Instruments

Multiple sources of evidence were used for the study. These are summarized in figure 3-1 below.

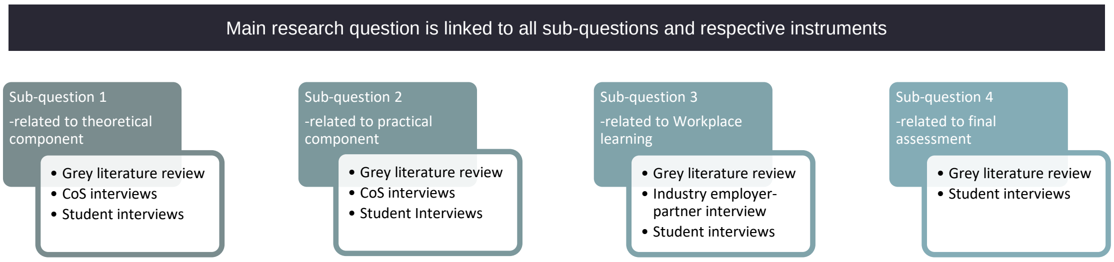

Figure 3-1 Overview of instruments and their links to research questions

Source: Author

i. Scholarly Literature

The literature review was undertaken to deepen and broaden the understanding of topics that are related to this research scope. The literature reviewed comprises of published scholarly work and non-scholarly reports published by authoritative sources. The non-scholarly reports were included as useful and supplementary knowledge that may not have been captured and published on scholarly platforms.

The literature was obtained from online databases such as Scopus, Science Direct, Google Scholar and ResearchGate. The search criteria employed was consistent with the sub-headings used for the paragraphs that follow in sections below. Some of the potentially useful papers may have been excluded from the review because payment was required for access to be granted. Specific websites such as that of the DHET were also used to access some of the published reports and papers.

ii. Grey Literature

Extensive review of published no-scholarly reports issued various agencies focusing on the development of TVET sector, innovation capability, and 4IR in South Africa was carried out. Such literature involved white papers, progress reports, and curriculum guiding documents among others.

iii. Semi-structured and Unstructured Interviews

In an effort to capture insights about realities and lived experiences by people located within the sectoral system, semi-structured interviews were conducted with representatives of colleges, industry employer (organizations), and near-qualification student. The semi-structured approach guided participants to the research's specific areas of interest while offering for a degree of freedom to discuss other activities, processes and relationships that are considered important. In cases where relevant participants or represented organizations did not have a direct or active role in the CoS program, unstructured interviews were conducted to gain insights that may assist in answering research questions.

The research instruments used for data collection are included in the appendix section. The instruments show main guiding questions for semi-structured interviews. However, there are a number of follow up questions not shown which were used to facilitate vivid explanation of participant insights.

3.5. DATA ANALYSIS

A deductive approach using theories that underpin this study was used. This approach uses a pre-existing theory as a basis for the analysis (Azungah, 2018). Thematic analysis was employed to analyze collected data. The process involved familiarization with study findings, generation of initial codes from the theoretical review, and merging those themes and concepts that emerged from collected data and those from studied literature.

3.6. LIMITATION OF THE STUDY

This study was designed to meet the strict time constraints imposed by the course academic calendar. The implication of this is that a relatively fewer number of cases could be used. As a result, it is understood that the two selected industry cases may not fully represent all thirteen priority skills that the DHET is focusing on developing, and that each skill may have unique considerations. This limitation is however acceptable within this research design, which is employing a qualitative methodology. Further research may extend the method to conduct more comprehensive and comparative assessments.

3.7. ETHICAL CONSIDERATIONS

Using the HREC (Non-medical) risk level categories, this study falls under the minimal risk category. The research was conducted within the guidelines given by Wits University Human Research Ethics Committee. Collection of data only commenced once the ethics review, approval process had been completed, and ethics clearance issued (Annex E). This process involved scrutiny of research instruments and the protocol used to ensure protection of those that were to participate in the study. Copies of research instruments used are shown under the Appendices section (Annex B-D).

3.8. RELIABILITY AND VALIDITY

A clear link has been drawn between the formulated research questions and data collection instruments. The embedded case study with two cases (Welder and Boilermaker Centres of Specialisation), colleges as the main cases and employer-partners sub-units of analysis were used for the study. Triangulation was also significantly exploited through the use of multiple sources of evidence. This involved review of grey literature, participant interviews, and written responses.

Collected data was stored in a password-encrypted folder and with organized subfolders on a laptop, used as study database. All literature contributing to the study is cited for traceability. The sources of interview responses and circumstances under which these responses were obtained are specified in chapter 4 while ensuring their anonymity.

3.9. SUMMARY

The research strategy and methodologies used for this study ensure integrity, validity and reliability of research results. The logic behind each choice was also justified through theoretical basis and prevailing contextual arrangements. Even though some of the representatives that were approached did not agree to participate in the study, this did not compromise the quality of the research. More details about the data collection process and outcomes are given in the following chapter.

4. Chapter 4: PRESENTATION OF RESULTS

4.1. OVERVIEW

This chapter gives a detailed account of data that was collected through the review of grey literature and interviews conducted. The processes and context within which the data collection took place are explained. The findings are first presented according to corresponding sources, and then organized with respect to each of the four research sub-questions, followed by the overall summary.

4.2. PRIMARY DATA DETAILS

4.2.1. Findings from interviews

The data collected through the interview process and written responses by respondents is presented under this section. The interpretivist approach was applied on received responses to develop coherent and consist meaning from expressions made by participants.

i. Summary of interview responses

The data shows that technology forms a significant part of the training for colleges and that this technology is consistent with that generally used by industry. This does not seem to be the case for the employer-partner. The college has also taken initial steps towards implementation of i4.0 technologies while none has been implemented. The feedback from the employer-partner indicates that no steps taken towards implementation of i4.0 technologies.

Table 4-1 below summarizes the feedback given by CoS1 respondents that represented both the college and employer-partner during interview processes.

	College	Industry Partner	Student
Level of incorporation of technology into practical training?	High	Low	Low
Notable advanced technologies available?	Inverter-based welding equipment with advanced controls	None - only conventional technology being used	None
4IR related technologies available?	Welding simulation	None	None
4IR related technologies incorporated into the theoretical & practical component of the training?	No – simulators were non-operational at the time of the interview	No	No
Used technologies consistent with technologies used by industry?	Yes	Not applicable	Yes
Ambitions to acquire to acquire any of the technologies?	Robotic welding system(s); CNC cutting system; Non-destructive testing (NDT) technologies	None specified	Not applicable
Students empowered for 4IR after qualification?	No	No	No
Immediate need to be addressed?	None specified	None specified	None specified

TABLE 4-1 COS1 RESPONSES

The CoS2 data shows significant use of technology by both the college and employer-partner. The technology used by the college is also consistent with what is generally used by industry. The employer-partner has implemented some of the i4.0 technologies in particular departments within the organization, but this is not the case for the college.

The summary of interview responses for the CoS2 is shown on the table 4-2 below.

	College	Industry Partner*	Student
Level of incorporation of technology into practical training?	High	Moderate	-
Notable advanced technologies available?	Computer Numerical Control (CNC) Profile Cutting Systems Digital Guillotine	PLC Incorporated systems CNC based systems	-
4IR related technologies available?	None	Virtual Reality (software simulation)	-
4IR related technologies incorporated into the theoretical or practical component of the training?	No	Yes	-
Used technologies consistent with technologies used by industry?	Yes	Not applicable	-
Ambitions to acquire to acquire any of the technologies?	Yes – Welding simulators	Yes – During the ongoing upgrades of manufacturing sites	-
Students empowered for 4IR after qualification?	No	Yes	-
Pressing needs to be addressed?	Incorporation of Computer Aided Drafting (CAD) module into the theoretical and practical training	None specified	-

TABLE 4-2 CoS2 RESPONSES

Similar to CoS2, the data collected from CoS3 shows significant incorporation of technology use by both the college and the employer-partner. The college seems to have made significant strides in acquiring i4.0 technology but has not implemented any yet. For this case, the technology used by the college was reported as not consistent with what is used by industry. However, it should be noted that not all technology currently used by the college was inconsistent with what industry uses. However, the question was answered as 'no' because of some particular technologies currently being used that were not.

Table 4-3 below summarizes interview responses for the CoS3.

	CoS3	**Industry Partner**[1]	**Student**
Level of incorporation of technology into practical training?	High	Moderate	Low
Notable advanced technologies available?	Digital guillotine	PLC Incorporated systems CNC based systems	Only tablets (for accessing learning material)
4IR related technologies available?	*All related to the 4IR Centre of Excellence project which is still in set-up phase:* Bionics & micro controllers; Automation Technologies; Connected learning; 3D printing; Intelligent Components & I4.0 Systems; Robotics; Networking & IT security; Virtual learning environments;	Virtual Reality (software simulation)	No

[1] The industry employer-partner interviewed represented both CoS2 and CoS3

	Digital Learning Portal;		
4IR related technologies incorporated into the theoretical or practical component of the training?	No	Yes	No
Used technologies consistent with technologies used by industry?	No	Not applicable	No
Ambitions to acquire to acquire any of the technologies?	No – but refer to the recently acquired tech equipment for 4IR Centre of Excellence project	Yes – During the ongoing upgrades of manufacturing sites	Not applicable
Students empowered for 4IR after qualification?	Yes	Yes	No
Immediate need to be addressed?	None specified	None specified	None specified

TABLE 4-3 COS3 RESPONSES

ii. Colleges

Responses highlight themes such as partnerships between colleges and industry organizations, peer-learning, incorporation of technology into the learning process, utilization and lack of 4IR awareness among learners.

The technologies that are available at colleges are largely because of **partnerships** that exist between colleges and international technology suppliers. In general, these partnerships were facilitated by existence of co-operation arrangements between the South African government and other states form part of the BRICS alliance. The technologies were acquired either as donations by these partners or purchased through funding made available by local organizations.

There was notable evidence of high value i4.0 technologies. This was linked to the 4IR Centre of Excellence project for which the college was getting itself geared up. The technologies had not yet been incorporated into the learning programs as this project was still in set-up phase. The college envisions that these technologies will be incorporated into existing CoS programs for trades they are specializing on once the set-up has been concluded.

There was also emphasis on the need to incorporate computer aided drafting (CAD) into their curriculum to ensure that the learners are better equipped for industry. They argued that their learners' experience was limited to working with pre-loaded designs that were supplied with the CNC cutting system software. Incorporating CAD software into the training would help broaden learner capabilities, as they would have a change to explore and simulate new ideas. This was mainly inspired by what they witnessed while visiting one of the international partner facilities, and how the learner program was run there.

Some of the learners whose contact details were given by respective colleges could not be reached for interviews. The interviewed students, who were close to completion of their three year programs, were initially not familiar with the concept of 4IR or I4.0 technologies. A simplified explanation was therefore given to ensure that the rest of the interview questions were properly understood. None of the students confirmed to have worked with i4.0 technologies during their time at the college or workplace.

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iii. Industry society organizations

One of the industry associations that participated in the interview process has some of the i4.0 technologies available in their facility where they also offer training services. The vast majority of their clients are industry organizations and individual clients. The organization was previously directly involved with the CoS program even though the person who was the one responsible for such activities was no longer part of the organization at the time of the interview. Currently the organization has no direct or indirect co-operation with any of the TVET colleges currently.

Notably, their recently launched robotics program had yielded less than desired traction from both public and industry thus far. No conclusive reasons were given to explain what could have caused this low interest. Furthermore, the interviewee mentioned that they were also aware of a TVET college that had access to some welding robots but had not incorporated these into their training program, generally expressing disappointment that such technologies were not finding good use within the training space in South Africa.

In a written response to a question about any interventions that the organization may have implemented to assist 4IR capability building, another industry association shared a copy of a White Paper on use and innovation of welding and joining technologies for improved global quality of life (Smallbone & Kocak, 2012). The paper was not prescriptive to training colleges nor to industry organizations but identified some of the industry challenges at the time and offered some possible solutions to respond to these.

In addressing the challenge of declining interest towards the welding trade and the aging of skilled welding personnel, which was prevalent in some economies, the paper put more emphasis in the role of industry in development of training programmes and appropriate incentives, which included tax relief for employers embarking on such initiatives.

With respect to leveraging ICT capabilities, the paper embraced, the pedagogical approaches that involved use of on-site training, e-learning, and video streaming to allow larger audiences to access training programs in countries where there is a notable demand. Some on the innovations that were named to improve efficient deployment of robotic welding included:

a) Automated process planning simulation,
b) Real-time-system monitoring,
c) Autonomous robot transport vehicle (RTV) navigation,
d) Industrially rugged RTV, torch collision units,
e) Contact sensors,
f) Laser joint tracking systems,

g) CAD-based system for simulation, and
h) Off-line programming

Other welding innovations included processes such as electrode beam, laser beam, hybrid laser and friction stir welding among others.

iv. Industry partner employers

One of the industry partner organizations interviewed was one of the biggest employers for the CoS program, involved in manufacturing of various steel products. The company cooperates with both CoS2 and CoS3. The organization had embarked on high investment upgrade of their manufacturing facilities. Implementation progress varied between manufacturing sites and departments and the project was reported to involve implementation of latest manufacturing technologies. Some of the technologies that were already implemented, which learners has access to included virtual simulation and incorporation of CNC & PLC based systems.

An industry organization working with CoS1 reported that conventional technologies were primarily used on the production shop floor, and that learners taking part in the program used the same technologies. The organization interviewed is in heavy equipment manufacturing business.

Quarterly held Reference Group Meetings were acknowledged as a helpful channel for communication between industry partners and colleges. The meeting, which is typically chaired by an industry partner to the college, is one of the key platforms where topics such as changes in industrial technological landscape can be discussed.

v. Other Sector-linked Organizations

To appreciate other efforts directed to 4IR capability building within the TVET sector, that may not necessarily be part of the CoS program, publicly available information was reviewed and some officials that were directly involved with specific projects were contacted.

One of the 4IR inspired pilot project known as Coded Welding was aimed at digitalizing education and training for the welding trade. The project was college-focused and open to any college that responded to the advertised call for applications. Among other considerations, the applicants were required to acquire or have access to simulation technologies, e-learning tools and training facilities. The pilot project was set to come to close in February 2023 and the official report published in couple of months.

Another 4IR-inspired project involving TVET colleges is the 4IR Centres of Excellence. At least nine TVET colleges across all provinces were already approved as 4IR Centres of Excellence.

4.2.2. Data from review of grey literature

Findings from review of regulatory and operational documents used by CoS program are presented below.

i. Curriculum structure and content

The QCTO and NOCC are the backbones of the CoS program. The former plays an oversight role for the design accreditation, implementation, assessment and certification of all TVET college programmes. The documents that were obtained through the QCTO website included the Curriculum Documents, External Assessment Specifications Documents, Occupational Certificates and the Learnership Registration Certificates for both welder and boilermaker trades. The QCTO curriculum structure is made up of knowledge, practical skills, and work experience modules. For welder trade, the curriculum is built upon the minimum requirements recommended by the International Institute of Welding that are to be used for training, examination and qualification of welding personnel. For boilermaker trade, inputs to development of the curriculum included registered South African fabrication qualifications, the two Canadian Red-Seal qualifications known as the Boilermaker and Metal Fabricator.

The NOCC also referred to as NOCC-A21, is based on the QCTO curriculum but was enhanced by incorporation of descriptive details such as duration and sequence of learning modules. This was done to ensure proper integration of workplace learning with knowledge and practice modules informed by the dual system apprenticeship model, while incorporating new industry methods. The CoS's studied are using the NOCC for their training programs. The contents of NOCC documents were reviewed for both the welder and boilermaker trades. The duration of this programme is three years for the welder trade, with 30% and 70% of the time spent at the college or training provider and workplace environment respectively. For the boilermaker trade, the split between time spent with the college or training provider and workplace is about 40/60, with significantly more time spent at the workplace during the three-year learning program. The boilermaker NOCC contains seven overarching learning themes, also referred to as learning areas. These are listed on the table 4-4 below.

Learning Area ID	Description
LA-A	Practice the occupation and behave responsibly and professionally in the work place.
LA-B	Handle and care for occupation-specific tools, equipment and machinery
LA-C	Conduct preparatory and quality assurance activities
LA-D	Preform different types of welding
LA-E	Perform different types of cutting
LA-F	Develop and lay-out components
LA-G	Fabricate, maintain and repair components and structures

TABLE 4-4 BOILERMAKER TRADE LEARNING AREAS

The five learning areas for the welder trade are listed on the table 4-5 below.

Learning Area ID	Description
LA-A	Practice the welding trade and comply with OHS Act and other regulations
LA-B	Plan, prepare and quality assure welding work
LA-C	Join metals using fillet and butt welds in different positions
LA-D	Cut, grind and gouge metals
LA-E	Preform different types of welding

TABLE 4-5 WELDER TRADE LEARNING AREAS

Each learning area is further broken down into smaller units of learning. These are Work Situations and have been profiled to develop learning area specific proficiencies through defined activities and respective durations. In total, there are 25 work situations for the welder and 32 for the boilermaker trade.

The curriculum content makes provision for learning through use of equipment and machinery that are required for performing occupation specific tasks. While this is the case, these provisions are silent when it comes to the level of smartness of such technologies. The types of equipment and tools that are to be used for learning activities have been profiled to a certain degree. However, the profiling level of detail varies among equipment and tools. For an example, the curriculum content for the welder trade does specify FCAW welding equipment as a resource required for performing welds using FCAW process. However, details about whether this equipment has to be transformer or invertor technology based, of analog or digital user interface, and whether the equipment has been enables for digital monitoring capabilities have not been specified.

Some features of advanced technologies such as automatic cutting equipment and CNC cutting have been incorporated into the knowledge modules but have not been made part of the practical and workplace learning modules. This means that one CoS could be using manual plasma cutting equipment for their practical modules and the other CNC plasma cutting system and both would be satisfying prescribed minimum requirements.

ii. Review of External Assessment Specifications

The external assessment specification documents for the welder and boilermaker trades are accessible through the QCTO website. A NAMB registered assessor at a QCTO registered center conducts the summative assessment generally known as the trade test, over a duration of 2 days or more, at the end on the program for each trade. The focus areas are summarized through table 4-6 below. Two of the studied colleges reported that they were in a process of obtaining accreditation as an assessment center in the near future.

Phase	**Assessment focus** *Welder*	**Assessment focus** *Boilermaker*
1	The ability to cut, gouge and gas weld ferrous materials	The ability to develop components.
2	The ability to weld ferrous materials including stainless steel using Shielded Metal Arc Welding	The ability to develop and fabricate using interpenetrations.
3	The ability to weld ferrous and non-ferrous materials using Gas Metal Arc Welding processes	The ability to mark-off and lay-out a construction.
4	The ability to weld ferrous and non-ferrous materials using the Gas Tungsten Arc Welding process	The ability to demonstrate an understanding of the underpinning theory of the boilermaker competencies

TABLE 4-6 FOCUS AREAS FOR BOILERMAKER AND WELDER TRADES

The assessment focus for both trades has been aligned to the foundational learning areas that would have been covered during the three-year learning course. Assessment focus areas have not specified in particular any emerging technologies for both occupations.

It is also worth noting that phase assessments, which are considered internal assessments, were introduced through NOCC and are used by CoS to evaluate the performance of learners progressively. This was reported to have yielded improved learner performance due to the much shorter time that lapses between learning and the assessment activities, compared if the assessment is carried out only at the end of the three-year program.

iii. Findings specific to research questions

Clarification of terms

As stated in chapter one, the technological innovations that the sub-questions refer to are those i4.0 technologies that are relevant to metal fabrication industry, which forms part of the manufacturing sector.

For the sections below, smart manufacturing technologies shall refer to additive manufacturing, smart robots, smart machines, advanced sensors, and other similar technologies. Smart computing technologies shall refer to advanced analytics, artificial intelligence, virtual reality applications, augmented reality applications, software simulation/modelling, digital infrastructure, real-time production activity monitoring, cloud computing and other similar technologies.

Borrowing the maturity levels approach used by (Siemens, 2017) and extending it to this context, the ranking for the level of i4.0 technology incorporation has been categorized as either emerging, developing, established or advanced. Table 4-7 below gives a more detailed description of each category.

Rank	Meaning
Emerging	No significant effort towards implementing industry 4.0 technologies
Developing	Embarked on initial steps towards implementation of i4.0 technologies
Established	Significant strides have been taken towards implementation of i4.0 technologies, but some room for improvement exists
Advanced	Full integration of i4.0 technologies, and regarded as mature

TABLE 4-7 RANKING FOR THE LEVEL OF INCORPORATION

[SOURCE: ORIGINALLY USED BY SIEMENS (2017). MODIFIED FOR APPLICABILITY TO THIS STUDY]

Ranking of the research findings will be based on evidence obtained from the primary data and subsequent interpretation by the author. In future, this tool can be further developed by also incorporating quantitative evaluation of conditions being studied.

Relating to Research Sub-question 1

RQ1 was concerned with the extent to which the theoretical learning component of the curriculum incorporates the sector-aligned technological innovations.

As shown on table 4-8 below, the level of i4.0 technology incorporation has been categorized as *emerging* for the theoretical learning component of the program for both trades.

	Welder Trade	**Boilermaker Trade**
Overall impression - I4.0 technology	Emerging	Emerging
Brief explanation	Curriculum content only refers to fundamental technologies, but not necessarily smart manufacturing or computing technologies	Some reference is made to advanced (CNC) systems but not necessarily smart manufacturing or computing technologies
Expected short-term improvements	No significant changes are expected to take place in the short-term	No significant changes are expected to take place in the short-term

TABLE 4-8 FINDINGS RELATED TO RQ1

Relating to Research Sub-question 2

RQ2 was concerned with the extent to which the practical training component of the curriculum incorporates sector-aligned technological innovations.

As shown on table 4-9 below, the level of i4.0 technology incorporation has been categorized as *emerging* for both trades.

	Welder Trade	Boilermaker Trade
Overall impression	Developing	Developing
Brief explanation	Newer generation of welding equipment with smart controls is being used, but not necessarily smart manufacturing or computing technologies Colleges are not obliged to use smart manufacturing or computing technologies. They may or not have access to these technologies.	Some advanced technologies are used by sampled colleges, but not necessarily smart manufacturing or computing technologies Colleges are not obliged to use smart manufacturing or computing technologies. They may or not have access to these technologies.
Expected short-term improvements	There is an ambition to acquire NDT and robotic welding systems, but timelines are not certain	There are significant improvements that are expected to take place. One CoS will soon commission technologies for the 4IR Centre of Excellence project and the other has ambitions to acquire welding simulators

Table 4-9 Findings related to RQ2

Relating to Research Sub-question 3

RQ3 was concerned with how the employer-partners (industry firms) have incorporated 4IR technologies into their business operations & training programs, to ensure that learners get exposure to practical applications and that they learn by using such technological innovations.

The findings are shown on table 4-10 below. When it comes to the employer-partner's level of i4.0 incorporation, the welder trade has been categorized as *emerging* while boilermaker trade was ranked as *developing*.

	Welder Trade	Boilermaker Trade
Overall impression	Emerging	Developing
Brief explanation	Only conventional technologies used by the sampled organization Employer-partners are not obliged to have or use smart manufacturing or computing technologies. Companies can decide to or not to have these capabilities	Advanced equipment and smart computing technologies are used in some departments of the sampled organization Employer-partners are not obliged to have or use smart manufacturing or computing technologies. Companies can decide to or not to have these capabilities
Expected short-term improvements	No significant changes are expected to take place at the sampled employer-partner in the short-term	The sampled organization is expected to extend implementation of i4.0 technologies to more departments.

TABLE 4-10 FINDINGS RELATED TO RQ3

Relating to Research Sub-question 4

RQ4 was concerned with how the final assessment component of the program considers the readiness and capability of learners to adapt to the anticipated technological and industrial changes propelled by the 4IR.

Table 4-11 below shows that both welder and boilermaker trades have been ranked as *emerging* when it comes to the level of i4.0 technology incorporation in the final assessment component.

	Welder Trade	Boilermaker Trade
Overall impression	Emerging	Emerging
Brief explanation	The focus of the external assessment does not involve smart manufacturing or computing technologies. The nature of exact technologies used may vary between approved assessment centres.	The focus of the external assessment does not involve smart manufacturing or computing technologies. The nature of exact technologies used may vary between approved assessment centres.

Expected short-term improvements	No significant changes are expected to take place. Certification some CoS as assessment centres may introduce technologies consistent with those that are used for the training. However, the nature of these technologies will still vary according to individual CoS capabilities.	No significant changes are expected to take place. Certification some CoS as assessment centres may introduce technologies consistent with those that are used for the training. However, the nature of these technologies will still vary according to individual CoS capabilities.

TABLE 4-11 FINDINGS RELATED TO RQ4

4.3. SUMMARY OF DATA PRESENTATION

The main research question was concerned with how well the components of the TVET system complement each other towards building the innovation capability necessitated by the Fourth Industrial Revolution.

The structural configuration of the CoS program allows for direct and formal learning channels between colleges and employer organizations. Learners spend significantly more time in workplace environments than in colleges. The interactions between colleges and employer organizations suggest the presence of strong linkages in cases where Memoranda of Understanding (MOU's) are in place.

Mechanisms such as Reference Group Meetings seem to play an active facilitative role for communication between industry and colleges. This can be a good platform to discuss technological changes and new training needs in the future, for both colleges and industry.

Ongoing knowledge and skills transfer taking place through partnerships between colleges and some international partners is another mechanism that can lead to implementation of technologies that can contribute towards capability building for 4IR.

The level of i4.0 technology incorporation with respect to the main four components of the CoS are ranked in table 4-12 below.

	Overall Finding[2]
RQ1 - related to theoretical knowledge	Emerging
RQ2 – related to practical learning	Developing
RQ3 – related to workplace learning	Developing
RQ4 – related to final assessment	Emerging

TABLE 4-12 OVERALL FINDINGS WITH RESPECT TO EACH RESEARCH SUB-QUESTION

While the curriculum is generally not explicit about access to and use of smart manufacturing or computing technologies, there are notable and active projects by colleges and employer organizations, in collaboration with SETA's, DHET and other partners, that aim to implement such technologies.

There does not seem to be coordination framework that ensures that various projects, which are taking place concurrently within the sector, are complementary towards 4IR capability building for the country.

The 4IR Centres of Excellence were not the focus of this research, however this project has significant potential to impact upon capability building for the country based on resources that are been made available and the observable level of implementation that has already been effected. During the course of this study it was not clear though as to how this project complements efforts directed towards development of the welding, boilermaking and other priority skills that are being developed by the CoS programme; and whether or not the project does focus on applications such as smart manufacturing.

[2] Refer to table 12 for detailed description of each category.

5. Chapter 5: ANALYSIS AND DISCUSSION OF THE FINDINGS

5.1. INTRODUCTION

The research results presented by the previous chapter will now be discussed and analyzed. The discussion synthesizes the research findings with the context of reviewed literature which pivoted about the foundational Sectoral Systems of Innovation and Production theory (Malerba M. , 2002), and intercepted by technological relatedness. Contributions to literature and new opportunities are also highlighted.

According to Bradley et al.(2007), defining initial codes is the first step when using a deductive approach to data analysis. Before carrying out review of data, preliminary codes were derived from reviewed extant literature. The conceptual framework and research questions also shaped the approach used for data collection including design of interview questions. During the data review process, specific attention was paid to identification of any new codes and themes that might emerge so that these could also be incorporated into the final code structure used for analysis of findings. The initial codes that did not find relevance with research findings were also discarded.

The link between research questions and the guiding themes that were used for data analysis and discussion is illustrated through the table 5-1 below. Findings are thereafter discussed in the context of each theme identified in the section that follows.

Guiding Themes	RQ1	RQ2	RQ3	RQ4	MAIN RQ
Basic technologies		✓	✓		✓
Technological relatedness		✓	✓		✓
Corporation structures					✓
Knowledge & Learning	✓	✓	✓	✓	✓

TABLE 5-1 LINKING GUIDING THEMES TO RESEARCH QUESTIONS

5.2. BASIC TECHNOLOGIES, RELATED LINKS AND DYNAMIC COMPLEMENTARITIES

5.2.1. Clarification of terms

For the purpose of this analysis the technologies used by various sectoral agents are categorized as conventional, advanced, and i4.0 technologies. It is important to simplify and make this distinction as discussions with some of the interviewees suggested that advanced technologies could easily be mistaken for i4.0 type technologies.

Conventional technologies can be considered as those that are capable of delivering basic output required to perform specific tasks such as measuring, bending, cutting, assembling, welding etc. They typically have been in existence for decades and do not feature any significant form of automation or digital interfaces. Typically, all operations are manual in nature and functions are interconnected.

Advanced technologies can be treated as those that more and above their capability to perform fundamental tasks, they have incorporated some form of digital interface to automate some or all of its operational functions. Some of the functions may still be manual, but the technology involves process repeatability and integration of various process activities.

I4.0 type technologies are those that specifically feature integration of humans, physical equipment, machinery or physical tools with digital or virtual spaces. It is also important to make the emphasis that i4.0 type technologies refer to the application or incorporation of enabling digital technologies into manufacturing operations (metal fabrication operations for the context of this research), and not just ICT capabilities by themselves. Examples include but are not limited to additive manufacturing, advanced robotics, collaborative robots, software-based simulation and industrial internet of things.

5.2.2. Discussion on collected data

Malerba & Nelson (2012) stressed access to complementary assets as important to catching-up. Similarly, it is important to prioritize access to i4.0 technologies to facilitate technical progress of the country. According to categories outlined in chapter 4 above, the i4.0, the technology level of incorporation was defined as *emerging* with respect to theoretical and final assessment components of the CoS program. The level of incorporation was categorized as *developing* with respect to practical and workplace components.

This data shows that none of the program components reflects evidence of having made significant strides in implementing i4.0 technologies. While this proves to be the case, there are promising elements that are informed by the revelation that some of the role players have taken initial steps towards implementation of i4.0 technologies. These findings are consistent with those of Maisiri & van Dyk (2019) which had found that 84% of the industry organizations were evenly split between *emerging* and *developing* categories.

The colleges have incorporated a mix of conventional and advanced technologies into their practical learning modules, with the latter more predominant. While the colleges have not yet (fully) incorporated use of i4.0 type technologies as part of their leaning curriculum, there is evidence of discussions and mobilization of resources by colleges to implement use of such tech technologies. The progress made in this regard varies among the studied colleges.

With learners spending a significantly larger portion of their time at the workplace during the three-year program than at colleges, it is reasonable to conclude that employer-partners are better positioned to play a more influential role in knowledge and skills transfer with respect to new technologies. Based on the data collected, the technology used by employer-partners varies from conventional only, to a mix of advanced and partial incorporation of i4.0 type technologies.

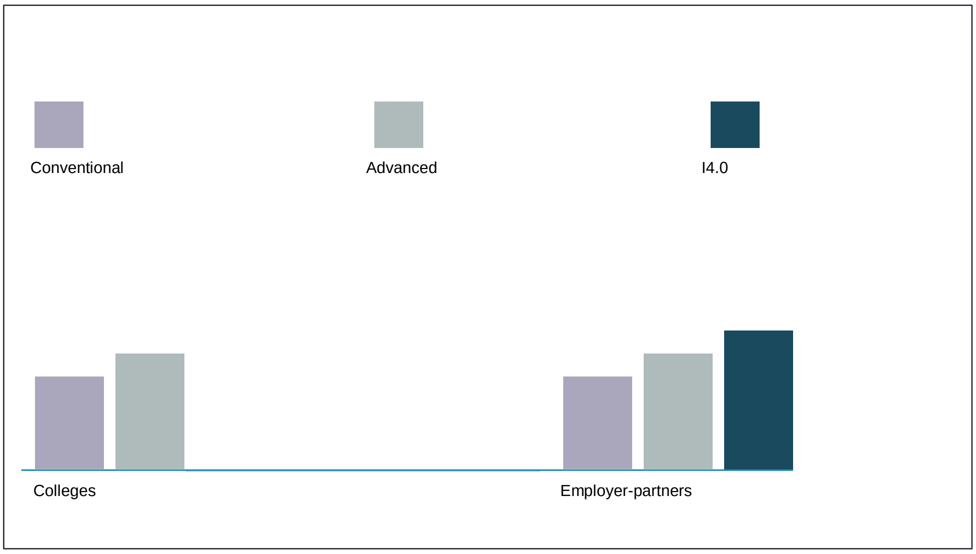

Figure 5-1 Typical mix of implemented technologies [Source: author]

Figure 5-1 shows the mix between conventional, advanced and i4.0 technologies that has been implemented by the studied colleges and employer-partners.

The data collected shows evidence of some complementarities that exist between colleges and industry employer-partners. For an example, some of the learners that are only using conventional technologies at their workplaces do get an opportunity to learn using advanced technologies while they are at the colleges, even though it is for a limited time. Another scenario that prevailed from the findings was that some learners who were not exposed to i4.0 technologies during their time at the college do get to work with these technologies at the workplace.

The variety of technologies used and industry segments within which the employer organizations operate suggest that learners employed by different organizations will not have necessarily received similar experiences by the time they complete the training program. Since the decisions related to technological innovation by industry organizations depend on various internal and external factors such as strategic intent, demand and competition forces, it can be expected that this inconsistency in type of technologies used is common throughout the sector. It is also not un-reasonable to imagine that there may be some industry organizations in existence that have significantly incorporated i4.0 technologies into their operations, but if so they are not involved with the CoS program.

5.3. TECHNOLOGICAL RELATEDNESS

The metal fabrication industry, which is part of the broader manufacturing sector, falls within the low aggregation frontier category in terms of technological hierarchies (Chatzistamoulou et al., 2022). This suggests that technologies used within this industry are characterized by relatively high level of relatedness. The research results imply that indeed the sector (colleges and industry) utilizes a related variety of technologies, which supports higher levels of knowledge and skills transfer within the sector through spillover effects.

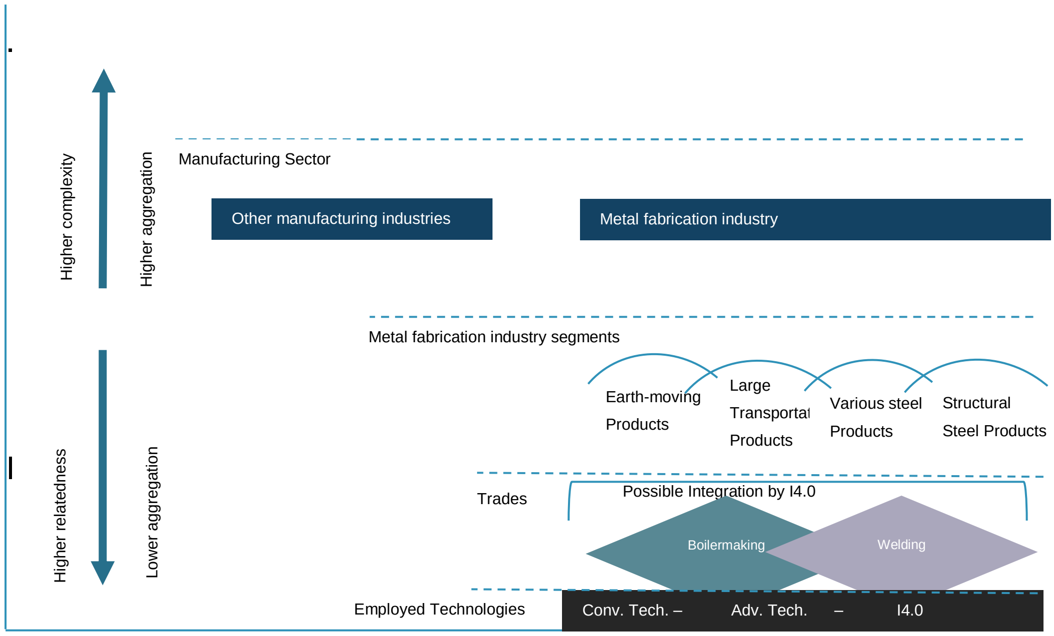

FIGURE 5-2 REPRESENTATION OF TECHNOLOGICAL RELATEDNESS

SOURCE: EXTENSION OF (CHATZISTAMOULOU, ET AL., 2022) HIERACHIES OF TECHNOLOGY BUT APPLIED TO FINDINGS OF THIS STUDY BY AUTHOR

Figure 5-2 gives a visual presentation of technological related observed from the findings.

Findings show a considerable level of overlap that exists between activities by learners who are following boilermaker and welding routes. This places both groups of learners within common learning environments. The related variety noted in terms of industry segments within which the employer-partners operate and the products they produce, triggers a new question about how this environment can be leveraged to maximize the learning potential.

However as mentioned above, these related technologies that are used largely comprise of conventional and advanced technologies. This can impede on efforts made towards building absorptive capacity in the context of 4IR, enabling path-dependency to re-inforce the stasis locking-out organizations from exploring opportunities that 4IR may open.

5.4. TYPES AND STRUCTURES OF INTERACTIONS AMONGST SSI AGENTS

The scope of this study included examination of activities by colleges and industry organizations directly involved with the CoS program. The work of other sectoral agents such as QCTO and DHET also formed part of the study.

As expressed by other scholars, the firms are key agents within the sectoral system of innovation (Malerba M. , 2002). They are involved with development, production, and use of innovations; and are regarded as purposeful innovating agents. Capability building by firms also have a more meaningful role for national economic catch-up goals (Kim, 1997). TVET colleges are key instruments that the South African government uses to develop skills for the country. A number of related strategic programmes are centered around these institutions.

The research findings confirm existence of strong interdependencies and active interactions between colleges and employer-partners. This takes place from the learner recruitment stage until the completion of the program by a learner. One example of instruments that help facilitate such interactions include the MOU, which is a formal arrangement between a college and the employer-partner. Another example are the regular Reference Group Meetings between employer-partners, colleges and DHET. Existence of such interactions offers a possibility of a faster flow of communication and alignment between the two key sectoral agents with regard to any topic of interest.

Another interaction that has assisted the CoS program is one that involves government (departments and agencies), technology suppliers and colleges. Acquisition of high value technologies used for the CoS program by colleges, and ongoing knowledge and skills transfer between suppliers and colleges can be attributed to this. Government departments or agencies' involvement included provision of funding for particular projects and establishment of inter-state support by BRICS member countries for an example. In one reference, a government agency (SETA) was reported to have played a facilitative role for non-CoS colleges to access CoS facilities for a particular project. Grants provision by SETA's also contribute towards the sustainability of the CoS program. These accounts point to positive nature of interaction among said parties.

There were also a number of other 4IR themed projects which were not directly linked to the CoS program, some of which were still at piloting stage. Some of these were strategic initiatives by SETA organizations and some by DHET. These projects were not the primary focus of this study; it is acknowledged that availability of information about some of these projects may have been limited because some projects were still being piloted. However, it is worth mentioning that this research did not identify any established links between the projects, which raises concerns about potential risk of failing to maximize synergies that could be leveraged through such initiatives.

The study did not establish whether mechanisms exist among employer-partners (and other industry organizations) to collaborate in situations where a particular employer-partner does not have adequate access to i4.0 technologies. There were also no specific collaboration channels that were identified between CoS colleges and privately owned training institutions such as those established by the big mining companies in South Africa, which in some cases may have access to some of the scars i4.0 technologies.

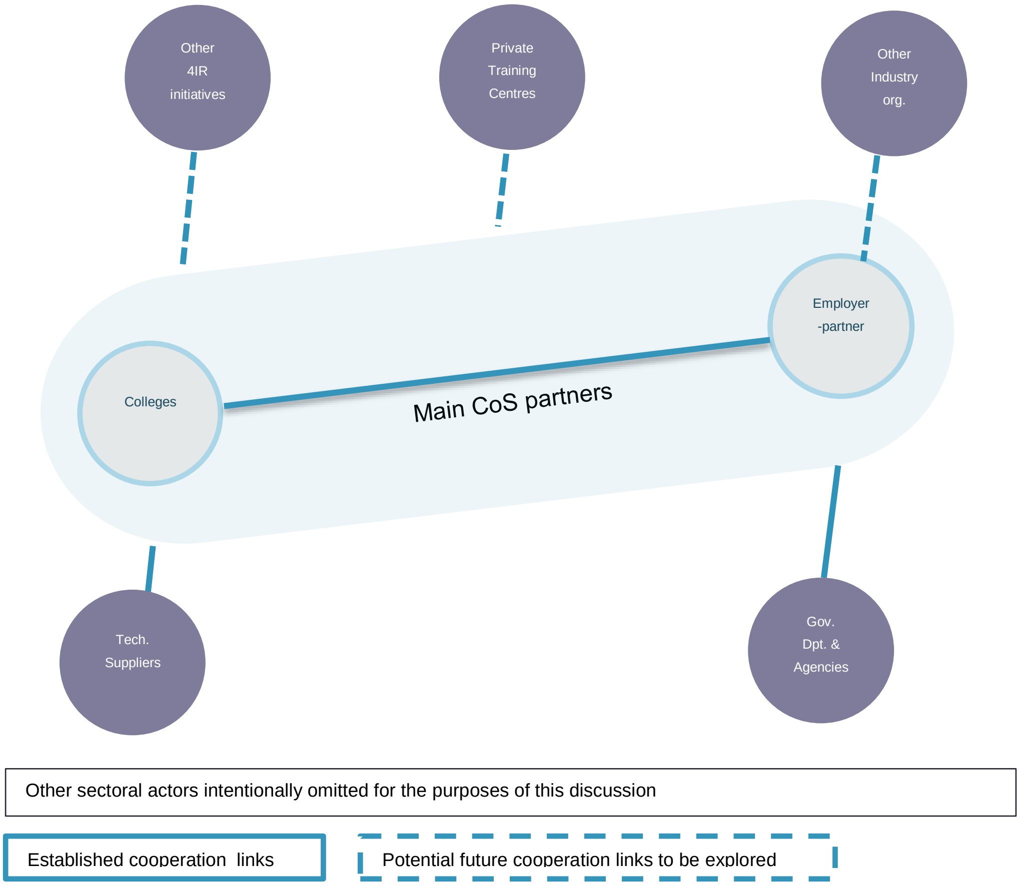

FIGURE 5-3 STRUCTURES OF INTERACTION [SOURCE: AUTHOR]

Figure 5-3 gives a visual overview of established and potential cooperation links that were identified during the study.

A point has been made in section 5.3 above about the overlapping activities between boilermaking and welding trades within an operational environment. This opens a discussion about how the activities linked with the two trades and others such as ICT could be coordinated in a more integrated manner to optimize innovation performance by firms through creation of new knowledge and skills spillover paths. I4.0 technologies offer a wide range of integration possibilities within the manufacturing sector. This supports an assertion made by Li et al. (2021) that 4IR does introduce modification of existing sectors and blurring of sectoral boundaries. A reviewed approach by and modification of communication structures among government departments & agencies, industry organizations, and technologies suppliers may be required in order to exploit the opportunity. The sectoral boundaries will likely be modified because of these new possibilities.

An unfavourable scenario exists in cases where a learner misses out on the opportunity to interact with i4.0 technologies during the time they spend in both the college and workplace environment. Modification to sectoral structure should prioritize avoiding exposing learners to this disadvantaged scenario.

5.5. KNOWLEDGE & LEARNING PROCESSES

The TVET sector is not directly involved with scientific research activities. Innovation related learning can be expected to mostly take place within a domain related to applications, uses and demand for sector products described, by described by Malerba (2002). As alluded in preceding sections, the majority of learners' time is spent at the workplace for the CoS program. Thus implying that the learning process can be largely elevated, and in some cases, restricted by the organizational capabilities.

Further, the innovative activities of the sectoral system can be explained by technological and learning regimes (Malerba, 2002; J. Lee & K. Lee, 2021). In other words, the prevailing regimes are expected to play a moderating role in the diffusion and use of i4.0 technologies by the TVET sector, which in this case is linked to South African metal fabrication industry. The technological regime dimensions include technological opportunities, appropriability of innovations, cumulativeness of technological advances, and properties of knowledge base (Breschi et al., 2000).

While learning at the workplace should accounts for the largest portion of the learning program, colleges also have an important role to play. Absorptive capacity is also enhanced by existing or prior knowledge. In other words, the learning that takes place at the workplace can be supported by that acquired at the college and vice versa. Literature suggests that incorporating technological innovations can enhance capability building in areas such as creativity (Li et al., 2022) and critical thinking (Meirbekov et al., 2022). While most colleges expressed keen interest to incorporate simulation tools into training modules, none of them were actively using such technologies at the time of the study.

5.6. SUMMARY OF THE DISCUSSION

The discussion contributed unique perspectives to the SSI, especially for the South African context. The four themes that guided the discussion were basic technologies, corporation structures; technological relatedness; knowledge and learning. In profiling the nature of technologies used in different areas of the CoS program, it is clear that there is still a considerable gap to be covered before reaching a point where the sector can be considered matured in terms of implementing i4.0 technologies.

The related variety of technology and industrial environments that exist within the studied sector opens up multiple opportunities that can be used to maximize the learning experience. Such possibilities can be realized through leveraging ICT capabilities, integration of related trade activities, and opening up of more collaboration channels among industry firms, between colleges and other private organizations, and between various sector projects that are setup to achieve similar objectives. Future interventions can easily build on top of some existing interaction structures that have proven to advance effectiveness of the sector thus far. Modifications in sectoral structures can be explored to expand the network of industry organizations that can directly and indirectly contribute towards developing 4IR capabilities.

The discussion also argues for the importance of investigating the technological dynamics that exist within the local industries, given the great influence that industry organizations has on the learning process and overall performance of the sector.

6. Chapter 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. INTRODUCTION

This research has been preoccupied with examining current settings and experiences within the TVET sector with the purpose of determining how the structural components of the sector work together in light of the anticipated industrial changes as a result of 4IR. The CoS program was used for sampling the sector while paying specific attention to industry employer-partners in addition to colleges, as the two core institutions driving innovation through the program. Expanding the application of Sectoral Systems of Innovations theory, the focus was on technological capability building by the TVET sector within the developing economy of South Africa.

The presentation and analysis of research results highlighted possible avenues as well as areas of concern that sectoral agents and research community can engage with to advance capability building and the innovation performance of the sector. Conclusions and recommendations are now going to be presented to sum up the research outcomes' implications.

6.2. MAJOR FINDINGS

6.2.1. Employer-partner in building innovation capabilities

The structure of the CoS program has positioned the industry employer as a key contributor towards learner development during the three year program. This structural arrangement gives employer-partners a more active role in building innovation capabilities within the sector. However, the reviewed scholarly literature and interventions by government and agencies are largely directed towards colleges and not so much in the employer-partner role. This study highlights the need to zoom into innovation capabilities of industry organizations that cooperate with colleges in skills development programs.

6.2.2. High technological relatedness but not leveraging i4.0

While there is evidence of initial steps being taken by some colleges to incorporate i4.0 into the basic technologies used for training, none have completed the integration. The level of implementation by industry employer-partners varies across organizations with confirmed cases of partial implementation. The studied CoS cases have strong resemblance of technology-related-variety between employer-partners and colleges.

This environment elevates the potential for knowledge transfer within the sector. However, this is countered by insufficient level of i4.0 technology incorporation by key role players. This finding suggests that more attention needs to be directed towards managing the risk of locking-out new technological knowledge, which would work against the innovation capability building process.

6.2.3. Extend partnering structures

Strong interaction and interdependency structures exist between the key CoS program partners such as colleges, employers, government agencies and technology suppliers. There is an opportunity to further improve existing structures, by extending the interaction and cooperation channels to other organizations that may have more developed technological capabilities. Similarly, new channels for cooperation can also be established and extended to other agencies that manage various 4IR related projects to ensure synergies are realized among various innovation agents.

6.3. KEY CONCLUSIONS OF THE STUDY[3].

6.3.1. Sub-question 1

<u>The RQ1 asked: To what extent does the theoretical component of the curriculum incorporate sector-aligned technological innovations?</u>

The theoretical component of the CoS program does incorporate sector-aligned technologies. However, the level of incorporation has been categorized as *emerging,* implying that there is no significant effort towards implementation of

[3] The technological innovations that the sub-questions refer to are those i4.0 technologies that are relevant to the metal fabrication industry.

i4.0 technologies. This is not a surprising finding when considering that curriculums are typically not updated on frequent basis.

6.3.2. Sub-question 2

The RQ2 asked: To what extent does the practical training component of the curriculum incorporate sector-aligned technological innovations?

The practical component of the CoS program does incorporate sector-aligned technologies. The level of incorporation has been categorized as *developing,* implying that there are initial steps that have been taken towards the implementation of i4.0 technologies.

6.3.3. Sub-question 3

The RQ3 asked: How have the employer-partners (industry firms) incorporated 4IR technologies into their business operations & training programs, to ensure that learners get exposure to practical applications and that they learn by using such technological innovations?

The industry employer-partners have been categorized as *developing,* implying that there are initial steps that have been taken towards the implementation of i4.0 technologies. Existing literature already indicates that 4IR related changes are highly path dependent. However, the reason behind this finding can be precisely explained through further research.

6.3.4. Sub-question 4

The RQ4 asked: How does the final assessment component of the program consider readiness and capability of learners to adapt to the anticipated technological and industrial changes propelled by the 4IR?

The final assessment component of the CoS program has level of incorporation categorized as *emerging,* implying that there is no significant effort towards implementation of i4.0 technologies. Learners are not specifically assessed for the context of 4IR. This research question is directly linked with RQ1. When the curriculum is not explicit about incorporation of i4.0 into the learning process, it is unimaginable that the assessment centres would seek to utilize such technologies.

6.3.5. The main research question

The main research question asked: How well do components of the TVET system complement each other, towards building the innovation capability necessitated by the Fourth Industrial Revolution?

Existing interdependencies and interactions between key components of the TVET sector in a CoS setting, provide an environment conducive for the transfer of knowledge. This is further bolstered by the technological relatedness that is evident among colleges and industry organizations. Capability building for the 4IR is however largely restricted by the fact that none of the key role players has reached either the *established* or *the advanced* stage when it comes to overall incorporation of i4.0 technologies.

6.4. RECOMMENDATIONS FOR STAKEHOLDERS

There is a need to extend sector interaction links to other organizations that are currently not part of the CoS program. Examples of such organizations include privately owned training colleges and industry firms that may have achieved *established* or *advanced* levels of i4.0 capabilities.

DHET and other government agencies such as SETA's can play an important role in integrating such organizations to foster new collaborations that can maximize synergies among various sector agents. Employer-partners can also explore possibilities for collaborating with other complementary industry firms that they can work with. Placement of learners should be arranged such that no learner completes their program having not interacted with i4.0 technologies at all.

Similar efforts are required to harness the capabilities developed by different 4IR related projects to benefit other initiatives that share similar objectives such as that of preparing workforce for the 4IR.

ICT capabilities offer new possibilities for integrating activities of trades that find themselves in related industrial application spaces. Trades such as boilermaking and welding have overlapping activities within both the learning and industrial application environments. The configuration and interactions between the CoS's of related trades can be re-considered to exploit possible sectoral complementarities.

The curriculum content needs to incorporate explicit guidelines about the nature and types of I4.0 technologies that colleges need to prioritize when acquiring such technologies. Guidance should also be given about how the i4.0 related technologies are to be incorporated into the existing training programs to ensure their effectiveness.

6.5. SUGGESTIONS FOR FUTURE RESEARCH

Future research should examine the nature of technological regimes that dominate the South African manufacturing industries. The data produced by such research will help provide reference and reasons for the technological trajectory of the country. This will also support the TVET colleges towards their objective of becoming more responsive to industry changes.

While college specific research is still needed for improved TVET sector performance, there is a need to focus the more energy towards the industry (employer-partner) innovation capabilities, which have a reciprocal and complementary relationship with development of absorptive capacity within sectors.

The methodology and theoretical frameworks used for this study can be extended to other cases that would represent other priority skills not covered by this research. The outcomes of such research can help identify emerging themes across all cases.

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8. APPENDIXES

APPENDIX A: Information Sheet for Respondents

11 February 2023

REQUEST FOR INFORMATION FOR A RESEARCH PROJECT

Dear Sir / Madam

My name is Thulani Mngomezulu and I am a Masters student in Innovation Studies at the University of the Witwatersrand, Johannesburg. As part of my studies, I have to undertake a research project. I am investigating Innovation capability building by the TVET sector for the Fourth Industrial Revolution in South Africa, under the supervision of Prof Geci Karuri-Sebina. The aim of this research project is to examine complementarity between the TVET colleges, their respective Centre of Specialisation program, and industry in the context of capability building for the fourth industrial revolution.

As part of this project, I would like to make a request for your organization to share information that has been specified on the accompanying email. The information requested is considered useful for the study at hand. There will be no costs to you if you participate in this project. You will not receive any direct benefits from participation but there are no disadvantages or penalties if you do not choose to participate or if you withdraw from the study. Your contribution will be completely confidential and your anonymity will be protected such that only the researcher will know your identity (the organization and person sharing the information). The information you give to me will be held securely and not disclosed to anyone else. I will be using a pseudonym (false name) to represent your participation in my final research report.

If you have any questions about this research, feel free to contact me on the details listed below. This study will be written up as a research report which will be available online through the university library website. If you wish to receive a summary of this report, I will be happy to send it to you. The data collected from this research project will be stored in a password protected laptop and folders and will be kept for a maximum period of one year. With your permission the data collected from this research project may be used by other researchers in an anonymized format. If you have any concerns or complaints regarding the ethical procedures

of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrecnon-medical@wits.ac.za

Yours sincerely,
Thulani Mngomezulu

Researcher: Thulani Mngomezulu, 2367565@students.wits.ac.za, +27 73 4645 236

Supervisor: Professor Geci Karuri-Sebina, geci.karuri-sebina@wits.ac.za, +27 11 7173 519

APPENDIX B: Semi-Structured Interview Questionnaire

Semi-structured Interview Sheet for the CoS

Title of project:

Innovation capability building by the TVET sector for the Fourth Industrial Revolution in South Africa

Name of researcher: **Thulani Mngomezulu (Student No. 2367565)**

Interviewee ID:

Date:

Location:

Opening Remarks

Introductory questions

Question 1

Please tell me about your role within the college and your involvement with the training program.

Question 2

Kindly take me through the process of the program from when you first get involved until the point of your last interaction with the student.

Technology specific questions

Question 3

How much focus has does the practical training incorporate new technology?

None		Minimal		Moderate		High	

Question 4

Can you elaborate on the answer given above?

Question 5

Is the college utilizing any of the technologies listed below?

Technology type	**Please give details**
Autonomous robots	
Collaborative robots	
Augmented Reality	
Simulation e.g. virtual reality, modelling software etc.	
Smart/Intelligent equipment e.g. fitted with sensors, digital/software based etc.	

Tracking technologies e.g. cloud based production monitoring	
Other	

Question 6

Are these technologies part of the theoretical training as well (in practice)?

Question 7

How would you rate the level of understanding of these technologies by trainers?

Low, support required		Moderate		High	

Question 8

Please elaborate on the answer given above

Question 9

Are you in a process of acquiring any of the other technologies over the next few months?

Generic open questions

Question 8

According to your own knowledge, are these technologies (that are used by the college) consistent with what industry is predominantly using, or exploring?

Question 9

In general, do you believe that qualified learners are well empowered to participate in new opportunities and deal with challenges ushered in by the 4IR when they enter the labour market? Or what in your opinion should be attended to as a matter of urgency to make possible?

Closing remarks

Thank you

APPENDIX C: Student Respondent Questionnaire

SEMI-STRUCTURED INTERVIEW SHEET FOR THE QUALIFIED/NEAR-QUALIFICATION STUDENT

Title of project:

Innovation capability building by the TVET sector for the Fourth Industrial Revolution in South Africa

Name of researcher: **Thulani Mngomezulu (Student No. 2367565)**

Interviewee ID:

Date:

Location:

Opening Remarks

Introductory Questions

Question 1

Kindly take me through your journey from when you started the program.

Question 2

Why did you join the program and how would you describe your experience until now?

Technology specific questions

Question 3

During the course of your training, which of the following technologies did you work with?

(Interviewer to explain each option to ensure proper understanding)

Technology type	**Please give details**
Autonomous robots	
Collaborative robots	
Augmented Reality	
Simulation e.g. virtual reality, modelling software etc.	
Smart/Intelligent equipment e.g. fitted with sensors, digital/software based etc.	
Tracking technologies e.g. cloud based production monitoring	
Other	

Question 4

During which part of the training did you work with these technologies?

Theory		Practical		Workplace	

Question 5

How would you rate your level of understanding of these technologies?

None		Minimal		Moderate		High	

Question 6

Please elaborate on the answer above.

Question 7

How much time did you spend working with these technologies?

< 4 weeks		More than 1 month, but less than 6 months		> 6 months	

Question 8

Did your final assessment involve any of these technologies?

Generic question

Question 10

What is next for you (after graduation)?

Closing remarks

APPENDIX D: Consent Form

Consent Form

Title of project:

Innovation capability building by the TVET sector for the Fourth Industrial Revolution in South Africa

Name of researcher: **Thulani Mngomezulu (Student No. 2367565)**

I, ……………………………………….., agree to participate in this research project. The research has been explained to me and I understand what my participation will involve. I agree to the following:

(Please circle the relevant options below).

I agree that my participation will remain anonymous	YES NO
I agree that the researcher may use anonymous quotes in his / her research report	YES NO
I agree that the interview may be audio recorded	YES NO
I agree that the information I provide may be used in an anonymized format after this project has ended, for academic purposes by other researchers, subject to their own ethics clearance being obtained.	YES NO

…..

…………………………………… (signature)
…………………………………… (name of participant)
…………………………………… (date)

…………………………………… (signature)
…………………………………… (name of person seeking consent)
…………………………………… (date)

Graduate School of Business Administration
University of the Witwatersrand, Johannesburg

Wits Business School

Wits Business School Ethics Committee
Constituted under the University Human Research Ethics Committee (Non-Medical)

Ethics Clearance Certificate

Ethics protocol number: WBS/IS2367565/138

This certificate is only valid with a legitimate ethics protocol number and signed by the Researcher (below).

This certificate is only valid if accompanied by formal permission from the relevant stakeholder(s).

Project title	Innovation capability building by the TVET sector for the Fourth Industrial Revolution in South Africa
Investigator / Researcher	Mr Thulani Mngomezulu
Nature of Project	MM (Innovation Studies)
Decision of the Committee	Approved, provided stakeholders and participants are guaranteed confidentialty.
Issue Date of Certificate	2023-01-19
Expiry date	Date of submission of the project / research report
Chairperson	Prof Anthony Stacey ☎ +27 11 717 3587 +27 82 880 4531 anthony.stacey@wits.ac.za

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Declaration by Researcher

One copy must be signed by the Researcher and returned to the Chairperson of the Wits Business School Ethics Committee.

I fully understand the conditions under which I am authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I undertake to resubmit the protocol to the Committee.

Signature

19 January 2023

Date:

APPENDIX F: TVET College Permission Application Form

higher education
& training
Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

DHET 004: APPENDIX 1:

APPLICATION FORM FOR <u>STUDENTS</u> TO CONDUCT RESEARCH IN PUBLIC COLLEGES

1. APPLICANT INFORMATION

1.1.	Title (Dr /Mr /Mrs /Ms)	MR	
1.2	Name and surname	THULANI MNGOMEZULU	
1.3	Postal address	7 TRAFFORD PLACE NORTH RIDING 2156	
1.4	Contact details	Tel	
		Cell	0734645236
		Fax	
		Email	2367565@students.wits.ac.za
1.5	Name of institution where enrolled	University of Witwatersrand	
1.6	Field of study	Innovation Studies	
1.7	Qualification registered for	***Please tick relevant option:***	
		Doctoral Degree (PhD)	
		Master's Degree	X
		Other (please specify)	

2. DETAILS OF THE STUDY

2.1	**Title of the study**
Innovation capability building by the TVET sector for the Fourth Industrial Revolution in South Africa	

2.2	**Purpose of the study**
This research seeks to establish how well the TVET sector, through the Centres of Specialisation program, is configured to enhance capability building for the fourth industrial revolution. The focus of	

the study will be on technological innovation capability building and knowledge spillover paths between the TVET colleges, industry firms (and training institutions associated with them), and the impact on innovation capability building within industry.

3. PARTICIPANTS AND TYPE/S OF ACTIVITIES TO BE UNDERTAKEN IN THE COLLEGE ***Please indicate the types of research activities you are planning to undertake in the College, as well as the categories of persons who are expected to participate in your study (for example, lecturers, students, College Principals, Deputy Principals, Campus Heads, Support Staff, Heads of Departments), including the number of participants for each activity.***

3.1	**Complete questionnaires**	**Expected participants (e.g. students, lecturers, College Principal)**	**Number of participants**
		a)	
		b)	
		c)	
		d)	
		e)	
3.2	**Participate in individual interviews**	**Expected participants**	**Number of participants**
		a) Project Manager (CoS)	1
		b) Facilitator (CoS – Welding)	1
		c) Students (age 18 or older) completed or close to completing the CoS program	2
		d)	
		e)	
3.3	**Participate in focus group discussions/ workshops**	**Expected participants**	**Number of participants**
		a)	
		b)	
		c)	
		d)	
		e)	
3.4	**Complete standardized tests (e.g. Psychometric Tests)**	**Expected participants**	**Number of participants**
		a)	
		b)	
		c)	
		d)	
		e)	
3.5	**Undertake observations** *Please specify*		
3.6	**Other** *Please specify*		

4. SUPPORT NEEDED FROM THE COLLEGE

Please indicate the type of support required from the College (Please tick relevant option/s)			
Type of support		***Yes***	***No***
4.1	The College will be required to identify participants and provide their contact details to the researcher.	*X*	
4.2	The College will be required to distribute questionnaires/instruments to participants on behalf of the researcher.		
4.3	The College will be required to provide official documents. ***Please specify the documents required below***		
4.4	The College will be required to provide data *(only if this data is not available from the DHET).* ***Please specify the data fields required, below***		
4.5	***Other, please specify below***	*X*	
	Part of my research requires me to interview representatives from employer-partners that work with the college on the CoS program. I will need the college to assist with providing contact details for these partners.		

5. DOCUMENTS TO BE ATTACHED TO THE APPLICATION

The following 2 (two) documents must be attached as a prerequisite for approval to undertake research in the College	
5.1	Ethics Clearance Certificate issued by a University Ethics Committee
5.2	Research proposal approved by a University

6. DECLARATION BY THE APPLICANT

I undertake to use the information that I acquire through my research, in a balanced and a responsible manner. I furthermore take note of, and agree to adhere to the following conditions:

a) I will schedule my research activities in consultation with the said College/s and participants in order not to interrupt the programme of the said College/s.

b) I agree that involvement by participants in my research study is voluntary, and that participants have a right to decline to participate in my research study.

c) I will obtain signed consent forms from participants prior to any engagement with them.
d) I will obtain written parental consent of students under 18 years of age, if they are expected to participate in my research.

e) I will inform participants about the use of recording devices such as tape-recorders and cameras, and participants will be free to reject them if they wish.

f) I will honour the right of participants to privacy, anonymity, confidentiality and respect for human dignity at all times. Participants will not be identifiable in any way from the results of my research, unless written consent is obtained otherwise.

g) I will not include the names of the said College/s or research participants in my research report, without the written consent of each of the said individuals and/or College/s.

h) I will send the draft research report to research participants before finalisation, in order to validate the accuracy of the information in the report.

i) I will not use the resources of the said College/s in which I am conducting research (such as stationery, photocopies, faxes, and telephones), for my research study.

j) Should I require data for this study, I will first request data directly from the Department of Higher Education and Training. I will request data from the College/s only if the DHET does not have the required data.

k) I will include a disclaimer in any report, publication or presentation arising from my research, that the findings and recommendations of the study do not represent the views of the said College/s or the Department of Higher Education and Training.

l) I will provide a summary of my research report to the Head of the College/s in which I undertook my research, for information purposes.

I declare that all statements made in this application are true and accurate. I accept the conditions associated with the granting of approval to conduct research and undertake to abide by them.

SIGNATURE	
DATE	20 January 2023

FOR OFFICIAL USE

TITLE OF STUDY:

………

DECISION BY HEAD OF COLLEGE

Please tick relevant decision and provide conditions/reasons where applicable		
Decision		***Please tick relevant option below***
1	Application approved	
2	Application approved subject to certain conditions. ***Specify conditions below***	
3	Application not approved***. Provide reasons for non-approval below***	
NAME OF COLLEGE		

NAME AND SURNAME OF HEAD OF COLLEGE	
SIGNATURE	
DATE	