Students' perceptions of the nature of technology and its relationship with science following an integrated curriculum

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Abstract

The increased emphasis on implementing effective integrated STEM education calls for in-depth student understanding of the nature of each separate discipline. This study examined how South African Grade 9 and 10 students who had completed 'Natural Sciences and Technology' as a school subject, perceived technology and its relationship with science in a South African context. Data were collected using a questionnaire with open-ended and Likert-type questions. We utilised Mitcham's typology of technology to analyse students' descriptions of technology, in combination with Gardner's framework to analyse how students perceived the relationships between science and technology. The results indicate that students hold narrow views of technology, mostly referring to technological objects and activities in their descriptions of technology, but neglecting technology as knowledge and volition. In terms of their perceptions of the relationship between science and technology, students hold several misconceptions. If we are to develop students' scientific literacy and technological capability, we need to ensure that students have opportunities to reflect and engage with the nature of and interactions between science and technology.

Keywords: *relationship between science and technology, student perceptions, the nature of technology*

Introduction

Integrated Science, Technology, Engineering and Mathematics Education (STEM) has recently gained prominence as an emerging pedagogical approach that aims to prepare students for the 21st century and beyond. In terms of a pedagogical approach, integrated STEM supports the idea that students are provided with opportunities to develop life-long learning skills such as complex problem solving of real-life problems, decision making, knowledge creation, collaboration and being capable users of technology (Dasgupta et al., 2019). With the increased emphasis on implementing effective integrated STEM education, supporting students to understand the nature of each STEM discipline becomes increasingly important (De Vries, 2019). To this end, this paper explores students' perceptions of the nature of technology and its relationship with science within the South African context.

The implementation of integrated STEM is not without its challenges. In implementing integrated STEM, some teachers have continued to focus on their traditional ways of teaching science and mathematics, ignoring technology and engineering components, which has resulted in a view that technology and engineering are subordinate (Pleasants et al., 2019; Williams, 2011). Other teachers harbour the misconception that technology only refers to educational technology devices with which teachers can support learning (De Vries, 2016), supporting a narrow view of integrated STEM education. In some cases, teachers merely view technology as design-and-make activities without the need to emphasise any scientific or mathematical knowledge (Banks & Barlex, 2014). At the heart of these challenges lies the differing interpretations of the meaning of 'technology' which have resulted in confusion and frustration amongst both teachers and students.

In the South African schooling system, the Intermediate Phase (Grades 4-6) occurs between the Foundation Phase (Grades R-3) and the Senior Phase (Grades 7-9), followed by the Further Education and Training Phase (Grades 10-12). Natural Sciences and Technology are compulsory components of the curricula for Intermediate and Senior Phases. In 2012, two school subjects, Technology and Natural Sciences were integrated into one subject in the Intermediate Phase. One of the reasons offered by the Department of Basic Education for this decision was "to help students achieve a thorough understanding of the nature of and connectedness in science and technology" (DBE, 2012a, p.9). However, the integration of science and technology into one subject has been controversial. On the one hand, scholars such as Lewis et al. (2007) argue that the integration of science and technology into one subject is illogical and dangerous to the education of students because of the individually different natures of the disciplines, while on the other hand, Tala (2013) maintains that difficulties in learning about the nature of science and technology is accelerated by the fragmentation of disciplines in education. Theoretically, both views hold merit, however studies are still emerging to empirically support each of these views. Currently there are limited findings to support curricula that offer integrated science and technology programmes, or for teaching the disciplines separately. This study is an attempt to contribute empirically to this debate.

Although there have been studies investigating students' perceptions of the nature of technology (DiGironimo, 2011; Firat, 2017; Jarvis & Rennie, 1996; Rennie & Jarvis, 1995; Rose & Dugger, 2002; Rücker & Pinkwart, 2018; Scherz & Oren, 2006; Svenningsson, 2020), and in particular, the nature of the relationship between science and technology (Constantinou et al., 2010; Rocha Fernandes et al., 2018; Ryan & Aikenhead, 1992) few studies report on the perceptions of students who have experienced an integrated science and technology curriculum. This paper aims to address the following two research questions:

1. How do South African Grade 9-10 students perceive the nature of technology?
2. How do South African Grade 9-10 students perceive the relationship between science and technology*?*

In line with Clough et al. (2013), we believe that the deeper students are immersed in a particular subject matter, the more developed their understandings about the nature of that discipline will be. These understandings, whether they are narrow or informed, will determine how they engage as active citizens with socio-scientific and socio-technological issues in their everyday lives (Waight & Abd-El-Khalick, 2012). If simplistic understandings about the nature of technology and its relationship with science are maintained, it could hold back qualitatively rich science and technology curricula development and thus have severe implications at classroom and policy levels (Keirl, 2018). More importantly, if we do not provide sufficient and adequate instruction on the nature of science and technology at the school level, the goal of developing scientific and technologically literate citizens might be compromised.

Literature review

Students' perceptions of the nature of technology

Increased focus on the nature of technology has only recently gained traction in comparison to the nature of science, which has been extensively emphasised in science education literature (Pleasants et al*.,* 2019). The current literature on the nature of technology draws significantly from philosophical, historical and sociological roots to describe what is regarded as technology, how and why technology develops, and what the nature of the relationships are between society, technology and the natural environment (De Vries, 2018; Pleasants et al*.,* 2019). In looking at the nature of technology from an educational perspective, scholars typically refer to the features of technological action, knowledge and values inherent in technological activities, and the technological outcomes that are conceived of, produced or maintained as a result of engagement in technological activities (Clough et al*.,* 2013; De Vries, 2018; Tala, 2013). It follows that knowledge of and capability in these features can support students in becoming technologically literate and informed.

Some of the first studies on students' perceptions of technology found that students have vague or distorted conceptions of technology (Wolters, 1989), and have trouble articulating its relationship with physics (Raat & De Vries, 1985). More recent studies have shown that although students have positive attitudes toward technology, they still demonstrate limited views of the nature of technology (Ankiewicz, 2019a). Both large and small-scale studies report that most students only view technology as modern electronic objects or machinery and equipment when asked what they consider as 'technology' (De Vries, 2016; DiGironimo, 2011; Jarvis & Rennie, 1996; Rocha Fernandes et al., 2018; Rose & Dugger, 2002; Svenningsson, 2020). There has been some development in students' ideas of technology as some studies have reported that students often mention manufacturing processes (DiGironimo, 2011), design and problem solving processes (Rennie & Jarvis, 1995; Svenningsson, 2020), application of knowledge (Rocha Fernandes et al., 2018) and technology as a human and social process (DiGironimo, 2011; Liou, 2015) with benefits and drawbacks (Constantinou et al., 2010; Pleasants et al., 2019). However, limited studies report on students' perceptions of technology after completing several years in an integrated science and technology curriculum.

Students' perceptions of the nature of technology and its relationship with science

Investigating students' perceptions of the relationship between science and technology remains an emerging field (Constantinou et al., 2010; De Vries, 2016; Hadjilouca & Constantinou, 2019; Rocha Fernandes et al., 2018). In characterising the relationship between science and technology, Gardner (1994) provides five different ways in which science and technology might be viewed by students:

1) Science and technology as *indistinguishable,* thereby seeing scientific and technological activities as the same thing;
2) Science and technology as *independent* disciplines with different goals and no relationship at all;
3) Technology as *applied science* in which all technological progress is dependent on scientific knowledge;
4) Science as *applied technology in which all scientific progress depends on technological tools and apparatus;*
5) Science and technology as *interdependent* in which progress and knowledge in science and technology support one another in a symbiotic relationship.

While examples of each of these perceptions exist, rendering the different perceptions plausible, an integrated approach to teaching science and technology would favour the last perception. If a student only holds one of the first four perceptions, their views about science and technology would be impoverished and possibly lead to misconceptions (Davies, 1997).

These views hold different implications for science and technology curricula (Davies, 1997), but not all these views have been explored in empirical studies. More specifically, the main focus of studies on students' perceptions of the relationship between science and technology has been on the distinction between the two disciplines (Constantinou et al., 2010; Ryan & Aikenhead, 1992). Students hold inaccurate or distorted views about the distinction between science and technology, which renders the disciplines indistinguishable from each other. In particular, students are unable to differentiate between the goals of science and technology and struggle to articulate discipline-specific procedures or objects of study in science and technology respectively (Constantinou et al., 2010; Ryan & Aikenhead, 1992).

Previous studies have also indicated that students view technology merely as applied science (Constantinou et al., 2010; Gil-Pérez et al., 2005; Rocha Fernandes et al., 2018; Sidawi, 2009). This view is an established misconception; however, the reason for students holding this belief has not yet sufficiently been explored. Studies on students' perceptions of the interdependent nature of science and technology seem to be limited, and few studies have explored how students view the relationship between science and technology.

Conceptual framework

For this study, we utilised Mitcham's (1994) typology of technology as a conceptual framework, illustrated in Figure 1. In his framework, Mitcham (1994), a well-known contemporary philosopher of technology, characterised four different ways in which technology manifests itself. This framework has been used extensively in the technology education literature to support the development of a philosophy of technology education (Ankiewicz, 2019b; De Vries, 2016; Svenningsson, 2019), the writing of technology curricula and policy documents (Nia & De Vries, 2016) and as an analysis tool for empirical studies (Ankiewicz, 2015; Svenningsson, 2020).

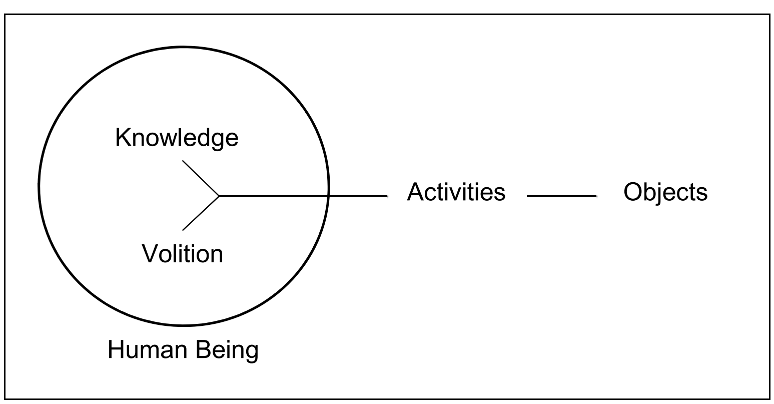

Figure 1: Four manifestations of technology (Mitcham, 1994)

According to Mitcham (1994), technology is constrained to human beings with specific needs, wants and desires, who possess the technical knowledge to engage in technological activities that are distinct from scientific knowledge (De Vries, 2018). This knowledge allows humans to produce and use technological objects (Mitcham, 1994). However, in practice, it is often difficult to distinguish between the two disciplines, especially in fields such as biomedical sciences and industrial research (De Vries, 2016). In the philosophy of technology, the specific nature of technological knowledge remains undefined (De Vries, 2016). It is generally accepted that when we develop students' technological capability, various knowledge types including factual knowledge, conceptual knowledge, procedural knowledge, metacognitive knowledge, experiential knowledge and contextual knowledge are developed (De Vries, 2016). The different knowledge types suggest that there are many forms of technological knowledge which students should be able to identify and demonstrate at the end of their technology education.

Technology as volition refers to the psychological capability of decision making and that human beings have the power to 'will' (Mitcham, 1994). Mitcham (1994) explores how technologies are connected to various types of will, for example, the will to: survive, meet needs and wants, control, and to be efficient or optimal (Keirl, 2018). In the context of technology education, volition refers to human beings' intentions and agency to design products, processes and systems to meet human needs and improve their general living conditions (Mitcham, 1994). De Vries (2016) notes that technology as volition has received the most attention in the philosophy of technology compared to the other modes of manifestation, but Keirl (2018) argues that it has been a neglected area in technology school curricula. From a technology education perspective, knowledge of technology as volition implies that students have an understanding of their own and other's technological being, efficacy, agency, decision making and critiquing abilities to transform their physical environment from an unsatisfactory situation, into a desired one (Ankiewicz, 2019a; Keirl, 2018; Mitcham, 1994). This implies that students would have an understanding of human engagement in technological activities such as designing and making with the intention and agency to improve or optimise their living conditions.

Technology as activity refers to events in which knowledge and volition combine to either create and optimise artefacts or to operate them (Mitcham, 1994). Essentially, Mitcham (1994) captures these activities as crafting, inventing, designing, manufacturing, operating, maintaining and evaluating. At the level of schooling, students are typically engaged in activities related to designing, making, critiquing and operating, but rarely in maintaining and managing activities. Technology as object refers to the material artefacts that are often the result or focus of engagement in technological activities such as designing, manufacturing, and optimisation (Mitcham, 1994). In studies on students' perceptions of technologies, technology as activities and objects are often used as examples to substantiate their understandings (Svenningsson, 2020); this is probably because technology curricula emphasise the designing and making aspects of technology the most (Keirl, 2018).

The benefit of using Mitcham's (1994) typology of technological manifestations is that it provides a holistic description of what technology could be, not only in terms of current and historical technologies, but also in terms of different types and levels of complexity in socio-technological systems (Svenningsson, 2020). In this way, Mitcham's typology highlights that the nature of technology does not only imply what technological objects are, but also emphasises how and why individuals develop, interact and are shaped by technology. Therefore, when engaging in technology education, students should be supported to become aware of the way in which technological objects, activities, knowledge and volition may affect their thinking, actions and values. As such, the content of technology education should enable citizens to make informed decisions about their interactions with technology in their personal lives, the natural environment and in society.

Methodology

For this study, we adopted a cross-sectional survey research design, which according to Lavrakas (2008), aims to collect quantitative and qualitative data to make inferences about a population at one point in time. This design allowed us to use a variety of open- and closed-ended questions to gather different types of data on the participants' perceptions of technology and its relationship with science. Data were collected by teachers acting as field workers, enrolled for a research module as part of their BEd (Honours) degree. Seven schools were conveniently selected based on their geographical proximity and the availability and accessibility of participants. The schools ranged from low- to well-resourced public and private institutions, situated in three provinces, Gauteng, North-West and the Eastern Cape. For this article we only report on the data collected on Grade 9 and 10 students' perceptions of the nature of technology and its relationship with science.

To collect data, we developed a questionnaire comprising both open- and closed-ended questions. We formulated five different open-ended prompts which required the participants to describe technology as they would to their friends, to provide examples of technological activities, to elicit their perceptions of the relationship between science and technology and of the differences between what scientists and technologists do. Five Likert scale items, based on Gardner's (1994) characterisation of science-technology relationships, were given to students to determine how they perceived the relationship between science and technology. This was supported by two qualitative questions to elaborate on their perceptions of the relationship between science and technology. By using open-ended questions as a data generation instrument, we enhanced the trustworthiness of the generated data, as it captured the participants' own and personal perceptions of the nature of technology and its relationship with science (Cohen et al., 2018). Teachers who were involved in data collection were trained to follow a structured procedure and no prompts or clues for answers were provided to the participants.

For data analysis, we followed Braun and Clarke's (2006) six phases of thematic analysis. We followed a combination of inductive and deductive thematic analyses, as it was compatible with our interpretivist stance. The flexibility of thematic analysis allowed us to transform the data into findings to address our research questions and descriptive statistics were used to analyse the frequencies of each statement of the quantitative data collected from the Likert scale.

Grade 9 and Grade 10 learner participants were selected purposefully since they would have completed three compulsory years in the integrated Natural Sciences and Technology subject (Grade 4-6), and three compulsory years in the separate Natural Sciences (Grade 7-9) and Technology (Grade 7-9) subjects respectively. In Grade 10, the participants did not study any technology-related content. As all the participants had completed their compulsory Natural Sciences and Technology content, they were treated as a single cohort of students as we did not expect substantial differences between the Grade 9 and Grade 10 participants. Out of the 203 learner participants who were invited to participate in the study, only 123 agreed to be part of the nature of technology questionnaire, and 125 agreed to be part of the technology and science questionnaire. Ethics approval and clearance for this research were obtained from all relevant authorities and the study adhered to the principles of informed consent, safety in participation, voluntary participation, privacy and trust (Cohen et al., 2018).

To enhance the dependability of this study we utilised an inter-coder reliability technique, i.e. a reliability technique in which corresponding codes can be found by two different coders in the same data set (Cohen et al., 2018). The consistency of the agreement between the two coders was determined by using the following formula (Jackson, 2006, p. 61):

$$\text{Inter-rater reliability} = \frac{\text{Number of agreements}}{\text{Number of possible agreements}} \times 100$$

$$= \frac{42}{50}$$

$$= 82\%$$

A review of the second coder’s classification revealed that the small disagreement noted above (18%) could be attributed to the way that the two coders initially interpreted ‘technology as volition’. During the mediation of the coding, agreement was reached to only code utterances as volition if agency and intention were implied. One coder initially considered “*The use of modern equipment such as cellphones, computer and tablets to make life easier for us”* as technology as volition. But during mediation, it was decided that the lack of agency and intention did not warrant such a coding. After mediation, agreement was reached for all coded responses.

Results

Student perceptions of technology

Participants' perceptions of the nature of technology were elicited through the question *“If you were to describe what technology is to your friends, how would you describe it?”.* The participants' descriptions were analysed according to Mitcham’s (1994) typology of technology and could include more than one manifestation of technology.

In agreement with previous studies on students’ perceptions of the nature of technology (De Vries, 2016; DiGironimo, 2011; Rose & Dugger, 2002; Scherz & Oren, 2006; Svenningsson, 2019), technology was mostly described in terms of physical objects or systems (mentioned by 78 participants in the data set) and technological activities (mentioned by 59 participants). There were also several descriptions that were classified as volition (21 participants) and knowledge (33 participants), which has not been a common descriptor used by participants in other studies on students’ perceptions of technology (Liou, 2015; Rennie & Jarvis, 1995; Svenningsson, 2019).

As each description of technology could contain more than one manifestation of technology, we wanted to explore the robustness of the participants’ descriptions. A Mitcham score was calculated for the data. Svenningsson (2020) suggests that a Mitcham score is calculated by assigning a score of 0 or 1 for each of the manifestations of technology that is present as object, activity, knowledge, or volition in the provided description. Next, the sum of the different manifestations is calculated, and a final score is given for a description that is between 0 to 4. The results of the analysis and the breakdown of each Mitcham score is shown in Figure 2.

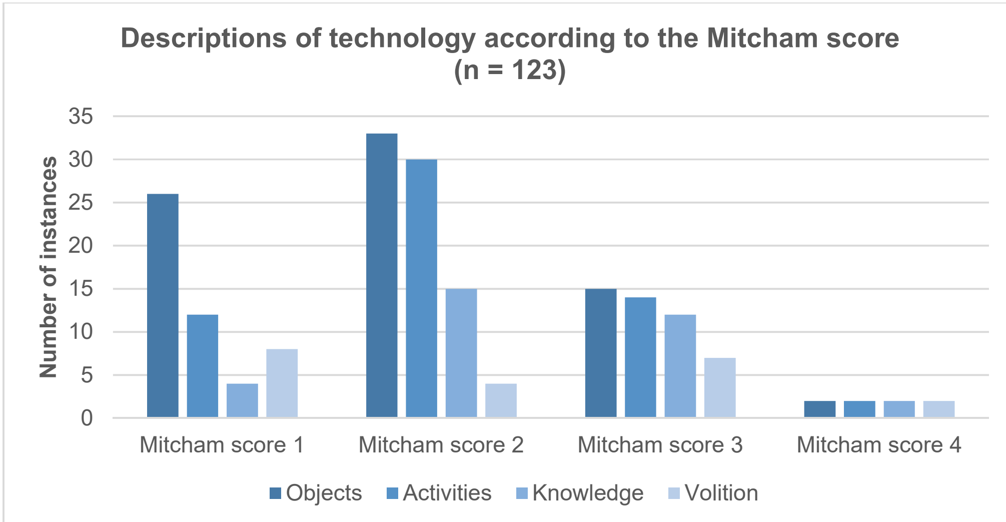

Figure 2: Participants' descriptions of technology according to the Mitcham score (Svenningsson, 2019)

This analysis suggests that students in this study held narrow views of technology. Figure 2 shows that most of the participants described technology with fewer than three manifestations of technology. In responses where only one manifestation of technology was mentioned, the majority of the participants viewed technology as objects, some defined technology as volition, or activities, but few described technology as knowledge. Where two manifestations of technology were referred to, objects were again mentioned most frequently, followed by activities and knowledge, but volition was neglected.

To understand students' qualitative perceptions of technology, we used an inductive thematic analysis to take a more in-depth look at students' descriptions of technology as objects, activities, volition and knowledge.

Technology as objects

Technology as objects was the most often mentioned manifestation of technology. The participants mostly referred to technological objects as a combination of everyday or specialised equipment with which they interacted. For example:

- *Technology are things like cars, phones and computers*
- *Machines, computers, circuits*
- *I would say that technology is the new way of doing things in the modern life like cell phones, microwave*

- *In my own words, technology is things that make our lives easier most of the products use electricity to perform its work.*

This result was expected as previous studies have shown that when people are asked to describe the concept of technology, they usually refer to technological objects (DiGironimo, 2011; Jarvis & Rennie, 1996; Liou, 2015). Most of the students' responses referred to digital, electronic or modern devices that are depicted / also occur in their textbooks, for example:

- *It involves the analysis of systems and the investigation of how many things work, for example, gears and pulleys as well as electronic circuits.*
- *Technology is divided into mechanical, electrical and civil objects.*

None of the responses referred to technological objects such as robotics, virtual reality or disruptive technologies. This could be explained by the absence of these concepts in their prescribed textbooks. It was interesting to see that there were only two participants who included a reference to the historical development of technology, but no specific examples were provided:

- *Any man-made object that does a job that needs force or energy to work.*
- *I would describe it as all things that have developed over the years, which makes our lives easier.*

This result confirms the findings of previous studies (DiGironimo, 2011; Firat, 2017; Lachapelle et al. 2019; Rücker & Pinkwart, 2018) who found that students do not regard objects that do not use electricity, such as clothing, furniture or that do not include complex mechanisms in their design as technological objects.

One participant mentioned that technological objects are only accessible to specific populations by stating that:

- *technology is using electronics for the privileged. Those goods using electricity.*

This statement indicates that technologies are often viewed as inaccessible to specific populations. Effectively, technological objects may be viewed as objects that are owned by the wealthy and to engage with technologies you need to have financial capital and have access to resources such as electricity. In the South African context, the socio-economic circumstances of students, even in the same classroom, may differ considerably, so that lack of electricity may be a reality for many students (Bayat et al., 2014).

Technology as activities

In their descriptions of technology, the participants referred to four different technological activities. The most common technological activity given by the participants was the use, working with and operation of technologies. Describing technological activities in terms of the use and operation of devices seemed to correlate with the fact that the participants mostly identified technological objects as technologies that they use daily.

- *I will describe it as technology as important to our country because it is the things that we use every day.*
- *Technology is the operation of mechanical objects used to make people's lives easier.*
- *Technology is electronic devices used to communicate.*

The participants also described activities related to designing and making. They used words such as inventing, imagining and planning, to refer to designing activities, and words such as building, producing and creating to refer to making activities.

- *It is the invention of stuff that can improve our lives.*
- *Technology to me is what we see, hear, touch in our daily basis, for example: buildings cell phones and robots. It is also about construction and design.*
- *I would say technology is generally the process of producing machinery for making life's tasks a little bit better.*

Lastly, only a few of the participants viewed technological activities in terms of optimisation, using words such as modifying, improving and advancement.

- *Technology is the advancement of equipment in order to help or better people's lives.*
- *Technology is a way of improving resources using less effort to carry bigger loads.*
- *How computers, cell phones and other digital objects are "modified".*

It is interesting to note that when the participants described technology in terms of technological activities, almost all of them only referred to one activity, either using, designing, making or modifying. Other activities such as technological evaluation, assessment, repair and maintenance as well as waste management did not feature in any of the responses. Perhaps, this might be because these concepts are not mentioned in the prescribed Natural Science and Technology, and the Technology curriculum (DBE, 2012a, 2012b), nor are these activities mentioned in the prescribed textbooks.

Technology as volition

Previous studies on students' perceptions of technology as volition have not yielded many results, as it is known that they do not really recognise technology as volition (DiGironimo, 2011; Rennie & Jarvis, 1995; Rose & Dugger, 2002; Svenningsson, 2019). However, in this study we found that students did indeed refer to this manifestation, for example:

- *Technology is used to create things that can help make the world and life easier and a better place.*
- *Technology is what we do to improve everyday life.*
- *Technology to me, I see it as a force which will help to innovate the world to be a better place.*

All of the responses contained some form of 'will' or agency, for example, the will to make life easier, the agency to improve current situations, or the will to innovate to make life a better place. The majority of the responses indicated that technology is created and used for altruistic reasons. However, there were two descriptions of technology, which demonstrated that technology could have both benefits and disadvantages:

- *I would describe technology as a tool that makes life easier for people and solves people's problems, but it can also kill at the same time. Technology can be a weapon.*
- *Technology is user friendly to all my friends, but it has its own disadvantages and advantages at times.*

Being able to critically reflect on the effect of technologies on the social and natural environment is one of the critical determinants of technological literacy (Pleasants et al., 2019; Tala, 2013), but in the case of our sample, there was limited evidence of this. Only two participants were able to recognise the role of society in shaping the kinds of technologies they need:

- *The application of science, math, art and other fields of knowledge to create tools and implements deemed useful by a society*
- *Technology is the use of skills, value, knowledge, and resources to reach people's needs.*

Although there was limited evidence of the participants' understanding of the role of technology on shaping society, some descriptions were given to demonstrate how technology is shaping society:

- *Technology is a span of devices that are created to do things without the help of human.*
- *Technology makes life better when it comes to mining, travelling, building etc.*
- *I would say that technology is crucial, we are nothing without technology. Technology is what we need in our country.*

These results pertaining to students' views of technology as volition contributes to the emerging field of students' perceptions of technology, as previous studies have indicated that the theme of technology as volition has received limited attention (Svenningsson, 2019).

Technology as knowledge

The participants' perceptions of technology as knowledge, skills and expertise were quite limited, with only a few descriptions including this manifestation of technology. Some students considered technology as a field of study or knowing how to do technology, expressed in the following examples:

- *Technology is the study of machinery, engineering and how things work.*
- *Technology is the study of technological development. This gives you the basic knowledge of how things work and how to make things.*
- *Technology is the theory behind construction and how to do the construction.*

- *Technology has to do with practical skills. For example, people that know how to design and manufacture products. I think it is hand-skills.*

The participants were able to distinguish between different technological knowledge contexts in terms of specific content areas such as mechanical, civil, electronic and electrical engineering, construction and computer science and engineering graphics and design knowledge.

- *Working and finding out more about electronics.*
- *I would say that it is a subject that teaches you about mechanical stuff.*
- *It is the knowledge of circuits, mining, all systems, and engineering drawings.*
- *It is a field of study that has to do with knowledge of design and programming.*

These responses are expected as technology as a subject in the South African education context explicitly refers to various technological content areas. These content areas include structures, processing, electrical systems and control and mechanical systems and control, civil technologies and computer applications technology.

Another theme that emerged from students' description of technological knowledge was their explicit acknowledgement of a relationship with science.

- *Inventing things using the laws of science.*
- *In technology we use scientific principles and apply them in a practical manner.*
- *Technology is the scientific study of mechanics and inventions. It is basically learning how materials operate.*

In all these examples, the students described a linear relationship between science and technology where science provides a basis for the development of technology and not a reciprocal relationship. This finding confirms previous work that has been done on students' perceptions of technology (DiGironimo, 2011; Gil-Pérez et al., 2005; Rocha Fernandes et al., 2018; Ryan & Aikenhead, 1992). However, we contend that there are more ways to characterise the relationship between science and technology and therefore we used Gardner's (1994) five characterisations of the relationships between science and technology to investigate students' perceptions. Despite the philosophical discussion and debate about the relationships between science and technology (Waight & Abd-El-Khalick, 2012; Radder, 2009; Tala, 2013), empirical results on how students perceive these relationships are still emerging.

Descriptions of the relationship between technology and science

In this section, we discuss the descriptive statistics of the Likert scale items and open-ended questions to determine how students view technology and its relationship with science. Figure 3 indicates the student responses to these statements.

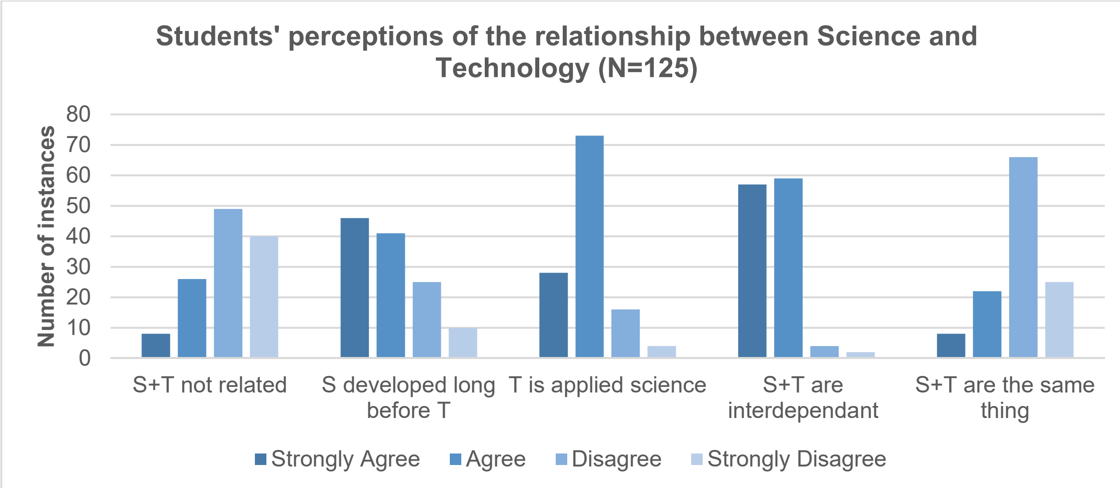

Figure 3: Students' perceptions of the relationship between science (S) and technology (T). These responses are based on Likert scale items.

While most of the students recognise that there is a relationship between science and technology, 34 participants described science and technology as two independent and unrelated disciplines. They demonstrated misconceptions about the relationship between science and technology as well as the nature of these subjects. Reasons for their beliefs were found in their responses to the open-ended question: *Are science and technology related? If you think that they are related, explain why you say that*.

- *No, because in science, you mostly work with chemicals while in technology, you create devices.*
- *No, because science is about natural things and technology is about new man-made things.*
- *No, in science we deal with investigating and technology deal with mechanisms.*
- *Science and technology are not related in any way. They are different.*
- *No, because science works with human organs and technology relates to inventing.*
- *In science, you discover what is present in human life and investigate why it is that way and how it works while in technology, we discover what is needed in human life.*

One specific misconception holds that science and technology are two distinct disciplines, based on their different foci: Science is only concerned with the natural world, while technology is focused on the man-made environment. In this view, science and technology do not interact.

A large number of the participant responses espoused the idea that technology only refers to new or modern objects and that science developed long before technology. In response to *science developed long before technology* most students agreed or strongly agreed. This misconception implies that science is the well-spring of technological innovation and should, therefore, be seen as a superior or foundational subject (Gil-Pérez et al., 2005; Sidawi, 2009).

Furthermore, this misconception was strengthened when the participants responded to what extent they agreed with the statement that *Technology is applied science.*

Out of a total of 125, 101 participants agreed and strongly agreed with the common misconception that technology is applied science (Constantinou et al., 2010; Gil-Pérez et al., 2005; Rocha Fernandes et al., 2018; Sidawi, 2009). Participants provided reasons for their beliefs in the open-ended questions:

- *Yes, because without science, technology would never have been created.*
- *Yes because science and technology grow together with science assisting technology.*
- *Technology is the practical application of science without science, technology cannot be developed.*

However, not all of the responses indicated that there only exists a one-directional relationship between science and technology and described an interdependent or bidirectional relationship. The majority of the participants agreed to the Likert scale item that *science and technology are different, but they support each other.* Responses in this regard included:

- *They are related because science needs technology and technology needs science. These two are part of STEM. They use each other's findings to help themselves find answers.*
- *Yes they are because to do technology you need some science techniques and to do science you need technology techniques such as circuits and forces.*
- *Yes, well in technology you need to know what kind of materials are suitable for usage and science determines the particles in the material and if it's going to support your material.*
- *Yes, to progress in science you do need the latest technology to do that. Technology progresses because science drives it to such an extent that it has to create something new.*

So, although science and technology possess their distinct bodies of knowledge, they interact in ways that have been described as a blurring of boundaries (De Vries, 2016; Sidawi, 2009).

Some participants (30 out of 125 participants) expressed uncertainty about the existence of differences between science and technology, implying that they do not acknowledge that technology has its own unique body of knowledge. This was unexpected since we assumed that the participants would have a firm understanding of the unique disciplinary content and interconnectedness between science and technology, as all of the participants had a compulsory school subject in which natural sciences and technology were combined (Grades 4-6) with the intention to "help students achieve a thorough understanding of the nature of and connectedness in science and technology" (DBE, 2012a, p.9). Despite their prior involvement in this subject, students remained unsure about the differences between science and technology, as reflected in the following responses:

- *They are the same because they teach us the same thing and they both solve problems with new things.*
- *They are the same. They talk about the same topics, just in different workbooks. Let's look at our natural sciences subject. It uses much information related to the one we use in technology. For example, circuits.*
- *They are because they teach you the same topic. You can become a scientist when you are doing technology as a subject.*

Based on the given responses, it seems that the participants experienced the learning content in the two subjects as similar. This is perhaps why Lewis et al. (2007) warns against the amalgamation of science and technology into one school subject. Although the idea of an integrated science and technology curriculum holds value in providing opportunities for students to engage in interdisciplinary learning environments (Tala, 2013), an informed understanding about the epistemological status of both subjects, as well as their underlying pedagogical content knowledge, is necessary.

Discussion

In this study, we attempted to elucidate how South African students perceive the nature of technology. The study confirmed the findings from other studies that students had narrow views of technology (DiGironimo, 2011; Ryan & Aikenhead, 1992; Svenningsson, 2020). In their descriptions, the majority of the participants only referred to two or fewer manifestations of technology, as measured by the Mitcham score developed by Svenningsson (2019). Furthermore, the majority of their descriptions referred to technology in terms of new electronic objects (DiGironimo, 2011; Lachapelle et al., 2019) and the technological activity of using, designing and making technology (Ankiewicz, 2019b). While other studies in the existing literature have been silent on the concepts of agency and the technological volition to affect change in the environment (Keirl, 2018; Svenningsson, 2019), in this study a few participant responses demonstrated that they were aware of these manifestations.

Technology possess its own unique body of knowledge, which integrates and transforms knowledge from other disciplines for functional means (De Vries, 2005). Only a limited number of participants seemed to show awareness of the nature of the relationship with other bodies of knowledge. However, those who did, saw a clear link between science and technology. In this way, this study confirms present studies on students' perceptions of technology as involving a link to science (Constantinou et al., 2010; Rocha Fernandes et al., 2018). In contrast, the existing literature remains silent on students' perceptions of the nature of the links with science and other bodies of knowledge.

We found that participants held varied beliefs of the relationship between science and technology. Departing from Gardner's (1994) framework, we found evidence that some of the participants could not distinguish between science and technology, while others believed that science and technology are distinct with different goals, purposes and foci. These findings contribute new insight into how secondary school participants, with a background in a combined science and technology school subject, view the relationship between science and technology. Although research on students' perceptions of science and technology relationships are still emerging, previous findings on technology teachers (Jones & Carr, 1992) showed that they often think that technology and science are indistinguishable. Perhaps the integration of science and technology into one single subject at the Grade 4 to 6 level has contributed to a misconception that these topics belong to a single discipline. The separation of the two bodies of knowledge in Grade 7 to 9 does not seem to have clarified the distinction between science and technology as separate disciplines in the minds of these students. This thus has implications for curriculum development in the South African context and could provide a cautionary note for the evolution of integrated STEM education.

It is significant that the views of students regarding the relationship between science and technology could be complicated by the erroneous views that students hold about the nature of science, as much as the views they hold about the nature of technology. The participant responses are indicative of such an interpretation when a student sees science as mostly chemistry and technology as mostly about the creation of devices. Such a response does not demonstrate a nuanced view of either science, nor of technology, and it is not clear to what extent these students limit the two disciplines to the activities that are described in their responses.

In line with these beliefs, common misconceptions about the relationship between science and technology emerged, namely, that science is historically superior to technology, and that technology is merely applied science. Our findings contribute to the emerging field of student perceptions of technology, as these views have mostly been confirmed in studies with teachers, but not by studies on students (Almutairi, Everatt, Snape, & Fox-Turnbull, 2014; Bouras & Albe, 2008; Yalvac et al., 2012). Although these misconceptions were triangulated in the Likert scale items and the open-ended questions, the majority of the participants conceded that science and technology are different, but they support each other. Compton (2004, p. 3) believes that such a perception can be beneficial for students as:

> *Scientific knowledge and methodologies themselves are useful, and in many cases critical, to students' successful undertaking of technological practice and in the development of technological knowledge. Technological*

> *knowledge, practices, and outcomes, in turn, can provide useful, and in many cases critical tools (both conceptual and material) for scientific practice and the development of scientific knowledge. Technological practices and outcomes can also provide authentic contexts which enable students to develop deeper understandings of scientific knowledge and methodologies.*

However, we believe that one of the reasons why some participants viewed science and technology as indistinguishable was based on how content knowledge is presented in science and technology textbooks. For example, multiple participants noted that you learn about mechanisms and electronics in both science and technology, and therefore they perceived science and technology as the same discipline. This seems to indicate that students and teachers alike should be educated about the nuanced ways in which science and technology content could be taught in their respective subjects (Hadjilouca & Constantinou, 2019; Lewis et al., 2007).

Conclusion

This study sought to investigate students' perceptions of the nature of technology and its relationship with science and confirmed that students hold narrow perceptions of technology. Furthermore, concerning their ideas about the relationships between science and technology, these participants held foreseen misconceptions. As a result, students might not be able to recognise the importance of being critical and reflective about their own and other's interactions with technology. Future studies could focus on planning and implementing design-based research projects in which interventions are developed for students as well as pre-service and in-service teachers. This is especially needed for countries such as South Africa, where science and technology school subjects are integrated into one curriculum.

If we are to develop students' scientific and technological literacy, we need to provide learning environments in which students have opportunities to reflect and engage with the similarities, differences and interactions between science and technology. These experiences should be conceptual and practical, bringing students to the converging boundaries of the made and the natural world, the real and the simulated and the currently impossible and the probable future realities (Compton, 2004). Both teachers and students need to engage with these converging boundaries if this is to be effected in future science and technology classrooms.

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