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How is the science concept of force conveyed in a physics grade 9 textbook in South Africa? A cultural historical analysis.

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Abstract

South African school children tend to perform poorly in international mathematics and science benchmarking tests such as *Trends in International Mathematics and Science Study* (TIMSS). Various reasons underpin poor performance, but in this paper, we concern ourselves with curriculum challenges in science by analysing a science topic from a Grade 9 science textbook, the most significant tool for delivering curriculum outside of a teacher. Adopting the model designed by Morris et al. (2016), we analyse a single topic, *force*, from two science textbooks to ascertain if the abstraction of the topic is explicated and whether it is linked to any real-world application. Our findings indicate that the science concept of *force* in the textbooks that we analyse is presented in problematic ways that require teachers to elaborate on concepts outside of the text, which may not be possible when such content knowledge is unfamiliar.

Keywords: cultural historical theory, everyday concepts, high school, simple science concepts, textbooks

Introduction

South Africa lags significantly behind other countries in benchmarking mathematics and science tests, such as *The International Mathematics and Science Study* (TIMSS) (van Standen et al., 2020). Further, tests of literacy in South Africa carried out under the *Progress in International Reading Literacy Study* (PIRLS) indicate that learners in Grade 6, that is, in primary school, are unable to read for meaning and cannot understand texts with which they interact (Mullis et al., 2017; Reed et al., 2020). Various reasons, ranging from a lack of human and material resources to teachers' lack of content knowledge in science have been indicated for this poor performance (Du Plessis & Letshwene, 2020; Hoadley, 2017; Howie et al., 2008; Kajiita & Kang'ethe, 2016; Muremela et al., 2023). The teachers' lack of content knowledge is of specific interest to us since teachers are the conduit through which learners co-construct meaning and understanding in any classroom. We argue that where a teacher lacks content knowledge in their subject (in the case of this paper in relation to science content) they are likely to rely heavily on what is provided to them in textbooks. However, where a textbook does not explicate science knowledge in ways that can make sense to learners and teachers, there is the potential for a teacher who lacks science content knowledge to provide only definitions of the work (which does not lead to acquisition) or, at worst, to misunderstanding the text.

Another reason for poor performance in science is the lack of resources to teach the subject in disadvantaged areas coupled with continuing socioeconomic disparities that arose from apartheid's unequal system (Du Plessis & Mestry, 2019; Hoadley, 2017; Howie et al., 2008; Magkato, 2007; Spaul 2015). Textbooks are the single central mechanism through which curriculum is presented to learners and teachers in classrooms, and this points to their importance in content acquisition. The significance of textbooks lies in their ability to fill, potentially, content knowledge gaps for teachers who may not have the requisite training in science (Macdonald, 2016). Textbooks, then, play a central role in what is taught in science classrooms and how this content is acquired by learners (Zorluoglu et al., 2016; 2020). We suggest that if a textbook does not adequately outline abstract concepts and harness learners' knowledge during acquisition, this will lead to a failure in acquisition. To ascertain the extent to which a textbook can do this in the Western Cape Province of South Africa, we address the following question.

> To what extent do two Curriculum and Assessment Policy Statement (CAPS) aligned and prescribed physics textbooks make the concept *force* available to students in Grade 9 in relation to the following questions:

- Does the text explain abstraction by elaborating concepts?
- Does the text recruit the everyday concepts of the learners to help them understand the abstract of science, and
- What is the cognitive level of questioning in the text that tests students' understanding of the concepts?

Literature review and theoretical framework: Outlining dialectical pedagogy

The present study is located in the cultural historical work of Vygotsky (1986) and his followers in that it speaks to what good developmental pedagogy should look like. For Vygotsky, pedagogy that develops a child cognitively is structured, or mediated, within a specific developmental zone that he called the Zone of Proximal Development (ZPD), where a more experienced other mediates a child's meaning-making (Hardman, 2024; Karpov &

Bransford, 1995). In dialogue, the teacher and the taught move from a place of not knowing to a place of new knowledge through the learner's acquiring what Vygotsky refers to as scientific concepts. A scientific concept should not be confused narrowly with a concept in science; for Vygotsky, this concept refers to abstraction, to something that cannot be empirically derived as distinct from spontaneous (everyday) concepts that emerge through empirical interactions in the world (Hedegaard & Edwards, 2024). For those working in a Vygotskian field, a scientific concept implies a single idea and is abstract but is not a science concept in the sense that it does not need to be open to experimental scrutiny. A concept combines two or more abstract and general attributes that are usually defined in a word, like, for example, photosynthesis. What is essential to abstract concepts is generalisation and abstraction since the generalised elements of the object are the content of the concept.

While the everyday concept moves upwards towards abstraction, the scientific concept moves downwards towards application. These concepts cannot be separated; without the abstract concept, the everyday remains beyond consciousness and without the everyday concept, the abstraction of the scientific concept is useless, hollow, and devoid of meaning. Everyday and abstract concepts are so intricately entailed in each other that Blunden (personal communication, 2023, November 27) suggested they are not two separate concepts but are, rather, two routes to a single concept. Proper acquisition of a whole concept requires that the scientific and the everyday are interpenetrated by each other. The abstract and the concrete (the scientific and the everyday) are interwoven in the acquisition of a valid concept. In the sense that a learner can apply abstraction to different contexts, we can say that the abstract moves down towards the concrete, rather than conceiving of learning as involving moving from the concrete to the abstract (Hedegaard, 2020).

In the dialogical transaction in the ZPD, meaning is co-constructed by teacher and taught, and knowledge is acquired. How then can a textbook open a ZPD? While it may not seem evident at first, a text, something we read, is, in fact, a moment for dialogue. The author of the text speaks, as it were, to the reader so meaning is created from the interaction between text and reader (Ricoeur, 1976). It is in this sense that the text is a potential tool for developing what Vygotsky calls higher cognitive functions and what we today would term executive functions. These are socially developed in interaction and are not present at birth. Books can serve as symbolic tools to develop executive functions in learners, depending on how they are written. Well-researched science textbooks contain varying examples, activities, prescribed experiments, and accompanying illustrations that are imperative to aid learners in visualising concepts (Macdonald, 2016; Vojíř, & Rusek, 2019). The need for textbooks to contain everyday examples is especially valid in the case of science subjects such as physics, where many studied concepts are abstract (Chi et al., 2024; Halawa et al., 2023). What all these studies refer to is the central role that a textbook can play in a classroom as a tool that teachers can use to deliver the curriculum. What these studies do not do, and what the current study attempts to outline, is how to judge a textbook's content from the perspective of the textbook as tool. This is where our work is relatively novel in that we adopt a Neo-Vygotskian framework to analyse the content of two science textbooks for conceptual acquisition. While there are studies that look at science textbooks in terms of how they represent women (Springston, 2023), for example, or how they represent science graphically (Vojir & Rusek, 2019), we can find no research that indicates how one can analyse the textbook as a *mediating tool* or, in other words, as a tool that can be used (or not) to develop children cognitively (Hardman, 2022) outside of the work of Morris et al. (2016) whose work we draw on in this paper. The novelty of this work, then, lies in the use of a categorical framework derived from engagement over years with the work of Vygotsky (1986) and Davidov (1990). We can find no work that uses a categorical framework, based on developmental theories, to analyse textbooks for the presence of scientific and everyday concepts as they are understood in cultural-historical work.

Given the potential of textbooks as mediators of cognitive development, we seek to investigate the extent to which prescribed textbooks outline one specific concept in science—*force*. We offer a brief caveat here in that we are not suggesting that a textbook can or should be a teacher (Zhu, & Tang, 2023). However, where a teacher lacks knowledge of the content being taught, as is the case in South Africa, they rely heavily in their teaching on what is contained in the textbook (Meza et al., 2022). In the absence of teachers' accurate content knowledge, we suggest that a textbook is a pedagogical aid in the classroom.

Theoretical moves

Using the work of Vygotsky (1986) and Morris et al., (2016) we analyse this topic with the explicit intention of investigating the extent to which the abstraction of *force* is made meaningful for learners in these textbooks. We are dealing with a textbook outside of a teacher's use of it. As indicated above, evidence suggests that teachers who lack content knowledge in science rely on textbooks to aid their pedagogy (Aydin & Turhan, 2023; Bergqvist & Rundgren, 2017). Suppose, however, that a textbook is not sufficiently elaborated in terms of defining and illustrating a concept. In that case, this may impact on a teacher's capacity to teach this concept if they reply solely on the textbook.[1] In this paper, we also look at the exercises in the textbook unit on *force* that test students' understanding of what has been covered. To do this, we use Bloom's taxonomy of questioning (Seaman, 2011).

While our work is founded on Vygotskian tenets, which lend themselves to what is sometimes referred to as a constructivist[2] paradigm, we are cognisant of the fact that Bloom's (1956) work is based quite narrowly on a behaviourist approach to teaching and learning (Zorluoglu et al., 2020). We do not use Bloom's work to comment on our analysis of the textbook but only to focus on the level of questions that are posed at the end of the unit we analyse to ascertain if the questions posed are developmental in the sense of being able to

1 We note here also that under COVID restrictions where schools in South Africa were closed for upwards of 2 years, schools that had no or limited access to connectivity gave textbooks to students for them to learn from in the absence of any teacher input. The importance of a textbook, then, as a pedagogical tool in our context is crucial, especially in times when teachers cannot connect with or contact students.

2 This term has suffered from overuse in educational writing, so much so that it has tended to lose coherence and has come to refer to any kind of action-based learning. We make it clear here that we take Vygotsky's work as constructivist, insofar as it refers to the recognition of children as active cognising agents who require guided assistance, or mediation, to develop cognitively. While children are born with innate capacities, these are altered through socio-cultural interaction with more knowledgeable others.

mediate higher cognitive functioning, that refers here to the development of executive functions such as working memory and attention. These functions are socially embedded and have a dialectical relation with the individual child's biological make-up.

Methodology

Since we focus on a *how* question, this paper is situated in a qualitative paradigm where meanings are investigated. This work draws primarily on Vygotsky's cultural-historical theory, which seeks to understand phenomena rather than quantify them, lending itself to an interpretivist methodological framework. Cultural-historical theory understands teaching and learning as dialectically entailed; one cannot separate the one from the other, except artificially.

Data collection

We selected two textbooks that met the following criteria:

- They are aimed at Grade 9 high school students.
- They were prescribed and approved for use in all schools by the South African National Curriculum and Assessment Policy Statement (CAPS).
- They introduce core concepts in science.

The choice of Grade 9 students was informed by the Piagetian understanding outlined in Piaget's Theory (1976) that children at this age and stage can think using formal logic and can formulate hypotheses to solve problems. These children are also not limited to understanding based on concrete instantiations of work. They are, therefore, able to work with abstractions, such as diagrams or high-level concepts in their work.

We chose *Natural Sciences Grade 9, Theory and Workbook* (3rd ed.) by A. Olivier (2021), (hereafter, Text 1) and *Solutions for All: Natural Science Grade 9 Learners' Book* by Brooksbank et al. (2013), (hereafter, Text 2) as meeting the criteria above.[3]

It is an onerous task to analyse an entire textbook, and we decided, therefore, to select a foundational concept in physics on which to focus our analysis. *Force* is a foundational concept relating to real-world phenomena and advanced scientific principles, and therefore, this topic met our need to select one that is central to physics while also being related to real-world applications so that everyday concepts could be analysed. Students must gain a sound understanding of *force* as they determine how objects move. Calculations and predictions of an object's trajectory are determined by understanding the relationship between *force* and *motion*. We decided to focus this analysis on a single lesson outline that introduces *force* as a concept in grade 9. While there are limitations to the narrow focus, we note that the form of how concepts are presented in both texts is consistent across the entire text and we may

[3] South African schools do not all use the same textbook for science, but this particular book is among the most used in the country.

anticipate that findings in relation to one section would be similar if not identical were we to analyse the entire module on *force*.

Analytical framework

Drawing on the principles of what constitutes a scientific concept, Morris et al., (2016) developed a conceptual framework to define a simple scientific concept. According to this framework, a simple scientific concept must contain two or more essential attributes (specialised terms that have universally accepted definitions) that are part of an ordered hierarchical knowledge system within which concepts are systematically interrelated and transferable across different concepts. A simple scientific concept should also contain two essential factors: content knowledge (knowledge about the topic being taught); and procedural knowledge (the mental activities and processes linked to acquiring content knowledge).

Finally, a simple scientific concept must provide the basis for building more complex scientific knowledge. We use the adjective "simple" here to signal that we are not looking for fully formed concepts since these take years to be developed but are looking for the beginnings of scientific concepts. This analysis seeks to understand 1) the extent to which scientific concepts, as defined by Vygotsky (1986) and drawing on Davydov (1990) in this paper, are made available to students through explication, 2) the extent to which everyday concepts are used in the textbook to make meaning more accessible, and 3) the extent to which the abstraction of the scientific concept is interwoven with the everyday concepts, making the knowledge applicable across contexts. Drawing on Morris et al. (2016), we used the following analytical indicators to analyse the textbooks.

Indicator 1: To what extent do the selected texts make simple scientific concepts available regarding:

- Use of and explication of specialised language;
- Relation of concepts to other concepts;
- Attributes of the concepts; and
- How the concepts are related to a broader context through the everyday concepts.

Indicator 2: How does the text represent the relationship between content and procedural knowledge in explaining the simple scientific concept?

- Indication of concept's use evident

Indicator 3: How does the text represent the relationship between the abstract, simple scientific concept and the everyday, empirical concept?

- Evidence of interpenetration of abstract concepts and everyday spontaneous concepts.

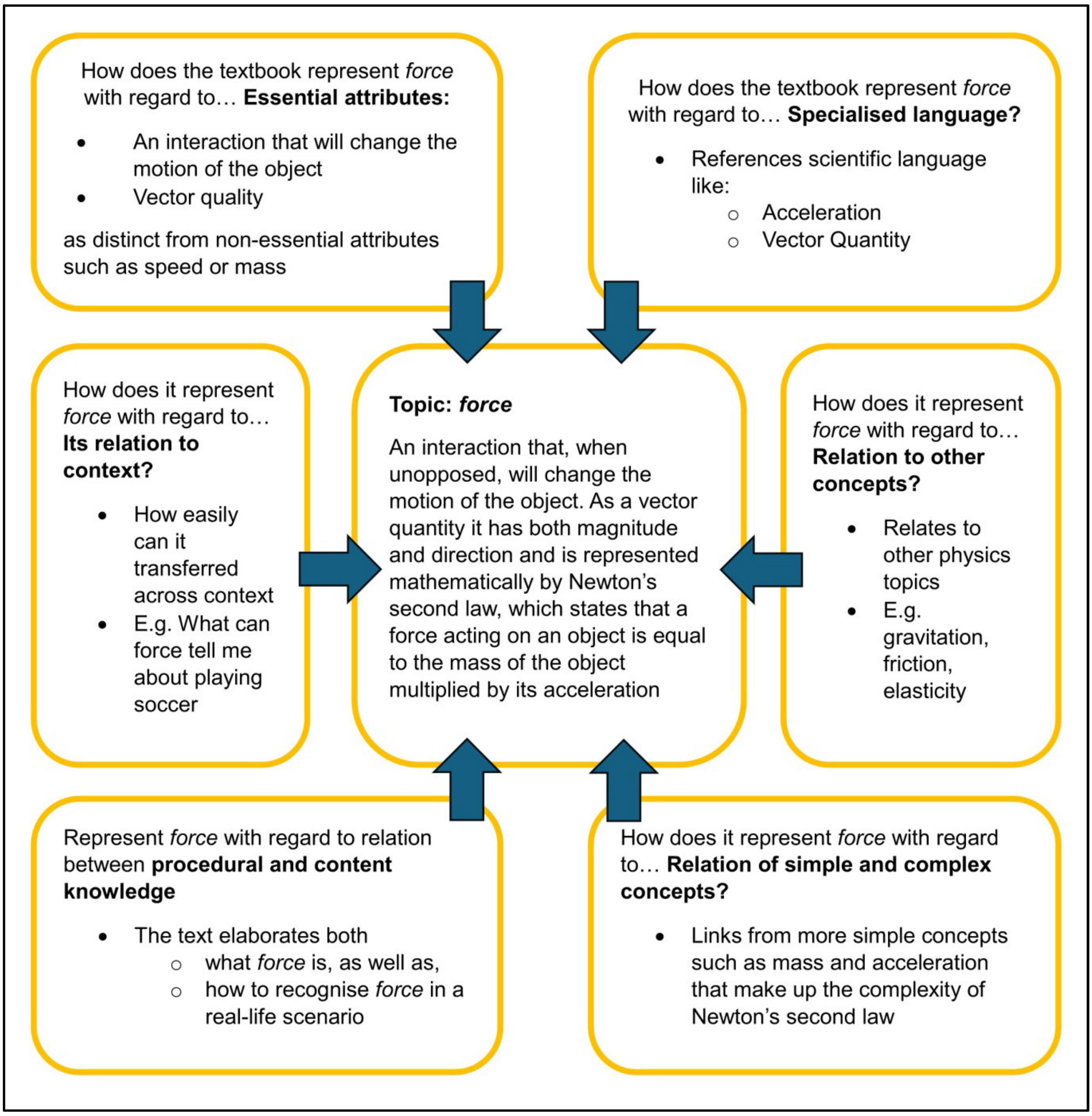
Table 1
Analysis Checklist

Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6
Contains two or more essential attributes that uniquely define and differentiate the concept from all other concepts	Employs two or more specialised terms	Described in relation to other concepts on the scientific knowledge continuum	Transfers across contexts	Structured as two integral parts (i.e. content knowledge and procedural knowledge)	Underpins more complex scientific concepts
/2	/2	/2	/2	/2	/2

Table 1 illustrates that

- a score of 12/12 indicates that the conditions for a simple scientific concept have been met and are explicit, complete, and coherent.
- a score of 5/12–11/12 indicates that conditions for a simple scientific concept have yet to be met but sufficient conditions have been met for a potential scientific concept to be developed.
- scoring 4/11 or below indicates that the concept is at the level of the everyday rather than at the level of the simple scientific concept. The location of this concept at the everyday level is partially problematic since it leaves the teacher in control of explicating the concept more fully for the learners. What this means, then, is that in the absence of the textbook making the scientific concept explicit, it is the teacher's responsibility to elaborate the concept. If the teacher does not have sufficient knowledge to do this, there is the potential of severe misunderstandings arising. An example of how one might hypothetically analyse the topic of *force* is reproduced in Figure 1 below.

Figure 1
Hypothetical analysis of *force*



Bloom's taxonomy

To analyse the questions that end the unit on *force* and are aimed at testing students' knowledge, we use Bloom's (1956) taxonomy illustrated in Table 2. Lower-level questions have a lower cognitive load than higher-level questions such as evaluation, which is illustrated in Table 3.

Table 2
Bloom's Taxonomy

	Category	Question style
1	Knowledge	Is it about remembering forgotten information?
2	Comprehension	Is it about grasping (understanding) meanings of the text?
3	Application	Is it seeking how to use known information in a new and concrete (ie single, best answers) situation?
4	Analysis	Is it about breaking down a text into component parts and examining them?
5	Synthesis	Is it about applying prior knowledge and skills to produce a new whole?
6	Evaluation	Is it judging the value of material based on personal values or opinions without right or wrong?

(Adapted from: http:IIfaculty washington eduIkrummeIguidesIbloom html)

Table 3
Cognitive Levels

Bloom's Questioning Styles

1	2	3	4	5	6

[Lower Order] [Higher Order]

Findings and discussion

Force is defined as an interaction that, when unopposed, will change the motion of an object (Shore, 2008). As a vector quantity, it has both magnitude and direction. It is represented mathematically by Newton's second law, which states that a force acting on an object is equal to the mass of the object multiplied by its acceleration. Mathematically, it is represented as F=m*a

Where

- F is the force,
- m is the mass, and
- a is the acceleration.

Text 1

We turn now to an analysis of the textbooks: the introduction to the topic of *Forces* in physics, Texts 1 and 2 must assume that learners do not have prior abstract knowledge of *force* and aim to bridge the gap between an everyday understanding (which can contain, potentially, individual misconceptions) to the scientifically correct one, that is, satisfying the criteria of a simple scientific concept. The given definition in Text 1 of a *force* is a “push or pull exerted on an object” (p. 75). According to the rating scale of forces in Table 1, “push,” “pull,” and “exert” are not specialised scientific terms but are, rather, everyday terms, although they provide a foundational understanding of what a force is; the definition of *force* is discussed but not in the abstract terms one would anticipate. However, it is important to note that scientific concepts have validity only in their application. Reliance on the everyday is therefore important to developing science understanding. However, if one does not interpenetrate the science concept with the everyday, the knowledge produced is lacking and remains based at the level of the concrete.

Push and *pull* are essential attributes of *force* but do not explicitly relate to other scientific concepts; some context is given in the definition, but it is only partially transferable to other contexts, and, since this definition is foundational, it has the potential to build on more complex scientific concepts. The definition provides some context but is limited for the broader application that is crucial to complex scientific concepts. In Table 1, this concept scores 1/2 (C1) because of two specialised but unexplained terms. For C2, it scores 2/2. There is no link to other scientific concepts, so it scores 0/2 on C3. While *push* and *pull* have everyday meanings, *force* does not, so this leads to a 1/2 on C4. There is no content-procedural knowledge link, so the score is 0/2 on C5. For C6, since *push* and *pull* lead to advanced concepts, it scores 2/2. Overall, this introductory text on *force* scores 6/12 in Table 1. Although potentially a scientific concept, it remains at an everyday level, lacking mention of *mass* and *acceleration*.

Following the introduction, learners are provided with pictures to illustrate the notions of *push* and *pull*, such as squeezing toothpaste from a tube, turning a bottle cap, stretching a rubber band, and kicking a soccer ball. One of the pictures in the textbook is represented in Figure 2. Note that there is no explanation about what is happening in Figure 1 and no reference to *force* in the actual picture nor in the text that follows the picture. The following description of *force* could accompany Figure 1

> A mechanical force, which is exerted by one’s fingertips, is applied to the tube of toothpaste when it is squeezed, resulting in a localised increase in pressure in the tube. A mechanical *force* can be represented as:

$$P=F/A \text{ or } P= FA$$

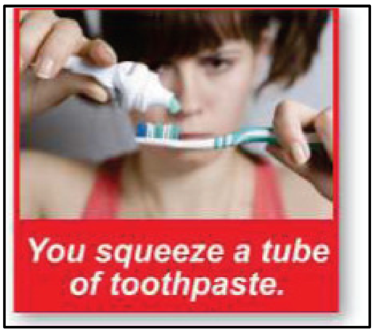
where

- P is the pressure
- F is the applied *force*
- A is the area over which the *force* is applied.

Squeezing the tube decreases the area A where the *force* is applied, increasing the internal pressure P. When the tube is squeezed, two main *forces* act on it.

- ***Compression Force***: The direct force applied by one's fingers to compress the tube and
- **Internal Pressure Force**: Pressure generated inside the tube pushes against the internal walls of the tube and the toothpaste, driving it outwards.

Figure 2
Squeezing Toothpaste



There is no scientific description of what happens when the tube is pressed, and the picture contains no abstract concepts that provide empirical everyday images of *force*. There is no scientific explanation related to the tube being pressed, and the picture shows only an everyday image of force. It scores 0/2 for C1 because there are no unique characteristics. C2 also scores 0/2 since specialised terms are not used to describe the action shown in the figure. The action shows *force* but is not linked to scientific concepts, so scores 0/2 for C3. Procedural knowledge is evident, scoring 1/2 for C4, but there is no content linking it to *force*. The examples are somewhat transferable, scoring 1/2 for C5. They do not underpin complex scientific concepts (C6). Pictures of *force* in action, for example a child pushing a toy cart, score 2/12, staying at an everyday knowledge level. There is no differentiation nor specialised terms, so this remains at the everyday level. There is no inherent problem with everyday concepts; without the everyday, we cannot understand abstraction. However, the everyday images alone, without any interpenetration with scientific concepts, keep the learners' understanding at the level of the concrete everyday world.

One may suggest that the pictures, for example the one that shows a person pushing toothpaste out of a tube, relate meaningfully to the terms *push* and *pull* used to introduce the notion of *force* but there is no link between the words *push* and *pull* and the actions shown in the pictures. The notion of *force* may have been better represented in the book if each picture had been set as an example of *push* or *pull forces*. An experienced teacher could use the pictures to prompt learners' thinking by asking questions such as: "Do you think this is a push or a pull?" and "Can you name other everyday experiences in which we apply force as a pull or as a push?" This level of engagement requires the teacher to go beyond the textbook and use their own initiative in teaching this concept. Where teachers have limited in-depth conceptual knowledge of science content, this will be impossible, and students will struggle to understand what *force* means (see Spaull, 2015).

Text 1 provides the following opening statement to further build on *forces*: "When a person studies forces and their effects, it is important to know what is exerting the force and on what it is exerted as well as in what direction" (2021, p.129) This statement is significant since it builds on the basic definition of *force*, adding elements like direction. For C1, we can say that the statement scores 2/2. For C2, it employs more than one specialised term, thus scoring 2/2. For C3, the concept is described in terms of other science concepts, such as direction, so gains a score of 2/2. The transferability of this knowledge across contexts (C4) is not made explicit, although it is inferred, so achieves a score of 1/2. Although satisfying most of the criteria for a simple scientific concept, the statement lacks explicitly described content and procedural knowledge (C5), scoring 1/2; both knowledge bases are inferred, knowing about forces and their effects and the necessity to understand direction and the agency of *force.* The complexity of this statement is underpinned by more complex concepts, scoring 2/2 for C6. This statement scores 10/12, which is potentially a simple scientific concept. Again, where the concept's potential needs to be realised in the teaching scenario, this relies on the teachers' knowledge to elaborate the concept further.

Extract 1
Text Box

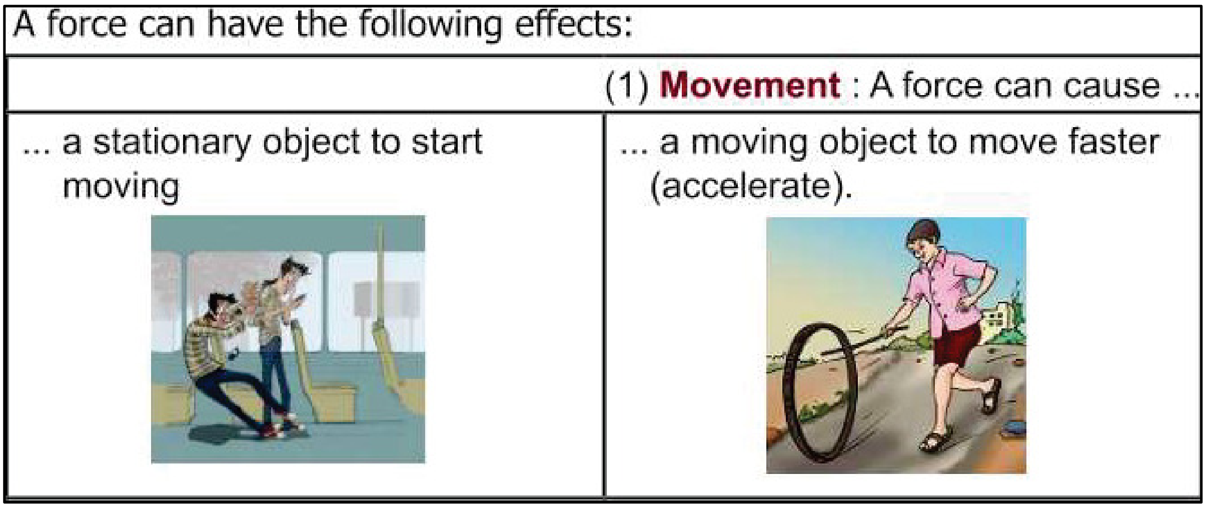
THE EFFECT OF A FORCE

- What forces do, is called the **effect** thereof.
- A force can not be seen, but the effect of a force can usually be observed.
- Sometimes a force exerted onto an object is too small to have a visible effect.
- In another instance two or more forces can be exerted in opposite directions so that they neutralize or balance one another's effect.
- In all these instances forces are exerted, but there is no perceptible effect.

The subsection, *The Effect of a Force,* is introduced with statements on the attributes of forces before providing the effects of forces, as illustrated in extract 1. The statements explain that even though forces are not visible, their effects usually are. These statements refer to two essential attributes of forces and meet the criteria with a 2/2 score for C1. The terms "forces," "effect," "exert," "neutralise," and "balance" are all accepted specialised scientific terms so here a score of 2/2 is achieved for C2. The mention of a "small force" (2019, p. 76) and forces being exerted in opposite directions relates to magnitude, and direction relates to other science concepts, so scores 2/2 for C3. There is sufficient reference to both content (what the effect of a force is) and procedural knowledge (how to observe and identify the effect) for this to score 2/2 for C4. In stating that some effects of forces are visible, and others may not be, the foundational idea of *force* being "conditions dependent" (p. 76) is created that is transferable across various physics contexts, scoring 2/2 for C5. These statements provide a basic understanding of how forces manifest under certain conditions. They make their effects observable and introduce concepts such as types of forces and force diagrams and vectors, thus scoring 2/2 for C6. Thus, these statements constitute a discussion of a simple scientific concept and score 12/12. Scientific language is used well in the analysed statements.

Following the *Effects of Forces* are several pictures under the heading: *Force Effects* shown in part in Figure 3.

Figure 3
Force Effects



Olivier 2019, p. 78

The pictures above are well presented with text that relates effectively to them, scoring an overall 11/12 for content knowledge. However, the section on procedural knowledge needs improvement since there is no link between content and procedural knowledge, thus scoring 1/2 for C4. Essential attributes in C1, like the effects of forces *(*movement*,* acceleration, deceleration, deformation, direction change, rotation), meet the criteria, scoring 2/2. Specialised terms in C2, such as "accelerate," "decelerate," and "deformation," are specific to physics, providing details on force effects, thus scoring 2/2. These terms are defined to help students unfamiliar with them. The captions explain how forces interact with stationary and moving objects, thus connecting to broader physics concepts, scoring 2/2 for C3. The illustrations and captions reflect real-world force effects, making this knowledge transferable, scoring 2/2 for C5. Detailed statements help learners to understand *force* and *motion*, Newton's laws, and *momentum*, studied in grades 11 and 12, thus they meet the criteria for a score of 2/2 for C6 by supporting more complex scientific concepts. This creates a seamless flow to higher-level concepts taught later. The illustrations show how science concepts relate to everyday objects, highlighting the dialectical relationship between abstract and everyday concepts.

Extract 2 shows the unit of *force* (Newton, N) that is introduced with captioned illustrations in the textbook.

Extract 2
Unit of force

THE UNIT OF FORCE

- The **newton (N)** is the **unit** in which **force is measured.**
- This unit is derived from the name of the English scientist, Sir Isaac Newton.

Context is provided since the unit of *force* is related to Sir Isaac Newton, and the illustrations provide examples of how force is exerted and measured in Newton, differentiating it from other concepts and scoring 2/2 for C1. The terms "Newton" and "kilogram" (in this context) are specific to physics, providing details on the measurement of force and weight, two scientific concepts, thereby scoring 2/2 for C2. By providing historical context with the mention of Sir Isaac Newton and relating *force* (an abstract concept) to a unit of measurement, this section relates to other concepts and scores 2/2 for C3. In describing the unit of Newton, content knowledge is evident. The captions accompanying the illustrations demonstrate calculations of force based on weight, providing procedural knowledge, making this transferable across contexts and scoring 2/2 for C4. The described examples are relatable to everyday experiences, allowing the reader to visualise and understand *force* while knowing how to apply it to other contexts, scoring 2/2 for C5. Understanding what the unit Newton is and how it relates to force will be used in understanding advanced topics of *force*, *motion*, and *energy* (C6). This score is 12/12, indicating the first presence of a simple scientific concept that does not need to be added to by a teacher.

Figure 4
Pushing on a wall

Figure 4 explains forces in pairs with examples of similar magnitudes and opposite directions, scoring 2/2 for C1. "Action Force" and "Reaction Force" are concrete physics terms, also scoring 2/2 for C2. Everyday examples, like pushing against a wall (Figure 4) relate to other concepts, scoring 2/2 for C3. Content knowledge that shows that forces always work in pairs, with procedural knowledge illustrated by examples for C4, scores 2/2 for C4. These examples help visualise and transfer the concept to other contexts (C5) since these are everyday examples (2/2). Finally, understanding how forces work is foundational to comprehending complex topics and calculations concerning *force*, *motion*, and *energy* (C6) (2/2). The textbook ends with exercises for concept application. Analysis findings of force in a Grade 9 textbook are represented in Table 4.

Table 4
The concept of force in a science textbook 1.

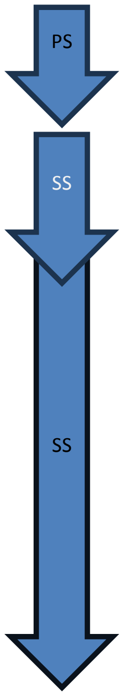
Concepts	C 1	C 2	C 3	C 4	C 5	C 6	Total	Concept type
Push and pull.	1/2	2/2	0/2	1/2	0/2	2/2	6/12	
Push and pull- Pictures 1	0/2	0/2	0/2	1/2	1/2	0/2	2/12	
Effect of force Text 1	2/2	2/2	2/2	1/2	1/2	2/2	10/12	
Effect of force text box 2	2/2	2/2	2/2	2/2	2/2	2/2	12/12	
Effect of force 3 [pictures]	2/2	2/2	2/2	1/2	2/2	2/2	11/12	
Unit of force 1	2/2	2/2	2/2	2/2	2/2	2/2	12/12	
Unit of force 2 [pictures]	2/2	2/2	2/2	2/2	2/2	2/2	12/12	

Table 4 shows that the concept of *force* is represented as a simple scientific concept related to the unit of force, both in text and in pictures, and the effect of force in 3. We may anticipate, then, that these elements of force will be relayed to students in the textbook in explicit and understandable ways. Three of the concepts introduced are simple scientific concepts, three are potential scientific concepts, and one is at the level of the everyday. We have noted that potential scientific concepts require teachers to elaborate the concept, something that is impossible if the teacher lacks this knowledge. This is the finding from only one textbook, though, and for comparison, we turn now to Text 2, which we analyse more succinctly since Text 1 was analysed in more depth to provide readers with analytical insight.

Text 2

In this text as in Text 1, *force* is defined as "a push or a pull" (2021, p. 129). A picture of a skater on roller skates is presented and learners are asked to say what is making the skater's hair flow in the wind. In relation to criterion 1, we can say that these are essential attributes of *force*, yet they lack the scientific definition and abstraction required, giving this a score of 1/2. Specialised terms are used and for criterion 2 we would rate this as 2/2, while for criterion 3, we would rate this as 0/2 since there is no linking to other scientific concepts, but the words push and pull can be transferred across contexts, giving a score of 1/2. There is no linking between procedural and content knowledge here, giving a score of 0/2 for criterion 5. However, *push* and *pull* do underpin other science knowledge and are therefore scored as 2/2 for criterion 6. In relation then, to the introduction and definition of *force* in this text we would assign a score of 6/12, locating this conceptual section at the level of a potential scientific concept that will require a teacher's further elaboration. However, the text then goes on to elaborate on a description of forces and here it moves to a more scientific and abstract notion of forces. The text indicates that "Force is measured in newton . . . force is always applied in a certain direction" (2021, p. 130).

What we have here is the use of two essential attributes of *force* (C1= 2/2) as well as the use of more than one specialised term (C2= 2/2). However, it is not fully explained in relation to other science knowledge and is scored therefore at 1/2 for criterion 3. The transferability of these concepts across contexts can be inferred from the text but is not explicit, thus scoring 1/2 for criterion 4. There is limited use of procedural knowledge linked to content knowledge so criterion 5 scores 1/2. For criterion 6, the text does underpin more complex scientific concepts and scores 2/2.

The text then moves on to illustrate the various effects of forces with several pictures representing different types of effects of *force*, such as a dog pulling on a lead, a boy exerting twisting force to dry a sponge and the force of brakes on a vehicle causing it to slow down and stop.

Figure 5
Illustration of Force

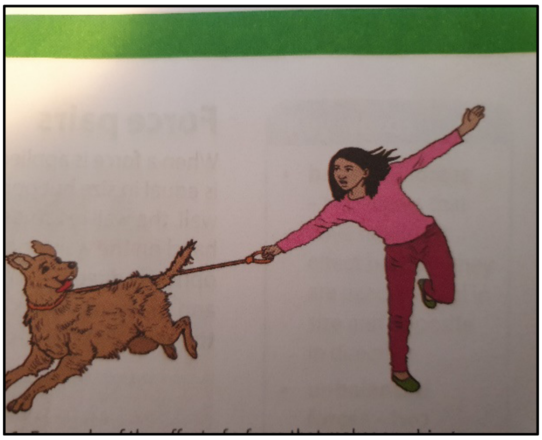


Figure 5 fails to illustrate an explanation of, or reference to, any abstract concepts with the notion of *force* located entirely in the everyday, so scores 0/2 for criterion 1. No specialised terms are used so C2 is scored at 0/2, and no relationship between these pictures and other scientific concepts is mentioned so scores 0/2 for C3. While there is evidence of procedural knowledge in the actions depicted, these are not related to content in any explicit manner, so score1/2 for C4. Since all the examples are everyday ones C5 is somewhat transferable across contexts, so scores 1/2. Criterion 6 is scored as 0/2 since these pictures do not underpin later scientific knowledge. For the effects of *force* in Text 2, we have a score then of 2/12.

Table 5
The concept of force in *Solutions for All Natural Science* (gr 9).

Concepts	C 1	C 2	C 3	C 4	C 5	C 6	Total	Concept type
Push and pull.	1/2	2/2	0/2	1/2	0/2	2/2	6/12	PS
Push and pull-defining force	2/2	2/2	0/2	1/2	1/2	2/2	8/12	pS
Effect of force pictures	0/2	0/2	0/2	1/2	1/2	0/2	2/12	eve ryd ay

While Text 1 did have some simple scientific concepts embedded in the work, Text 2 does not. Rather, there are potential scientific concepts (see table 5) and one everyday concept in Text 2. As noted earlier, a potential scientific concept requires that teachers have good content knowledge to elaborate on it. Where this is lacking, the concept may remain meaningless to the learners. The use of the everyday is important when it is intertwined with the abstraction of science concepts, yet on its own, reliance on the everyday as we see in the effects of pictures of forces leaves the knowledge context bound and abstractly opaque.

Bloom's taxonomy

Having analysed the text presented in the section on *force*, we now turn to the questions posed at the end of this unit to understand the cognitive level at which students' knowledge of *force* is tested. Pedagogically, in a classroom context in which a teacher engages in dialogue with learners, questions can scaffold their learning (Dillon,1984). When used to test students, questions are not necessarily used as teaching/learning tools but rather as a way of determining the learners' knowledge base. The focus on closed, single answer questions in testing is why we often see questions in tests that require memory instead of application. However, Bloom et al. (1956) developed a questioning hierarchy to determine the extent to which test questions probe students' more profound understanding, and we draw on this here.

Textbook 1's section on force ends with 28 questions comprising 17 sub-questions. Of the 28 questions most are lower-level knowledge questions, two are comprehension questions, and two are application questions as defined by Bloom's taxonomy outlined in Table 1. That is, 86% of questions were knowledge-type questions as illustrated in extract 3.

Extract 3
An example of knowledge (recall) questions.

3. In which **unit** is force measured? ______________________________

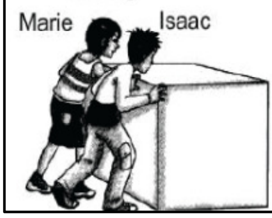
4. A force can be measured by a ____________ that is marked (calibrated) in ________.

5. Do single forces occur? Explain.

Comprehension questions began with the word "explain" (reference) and accounted for 7% of questions posed, and application questions constituted 7% of the questions posed. The application questions required students to use the concept in a new context, as illustrated in extract 4.

Extract 4
Application questions

10.3 Sketch on the figure below the direction in which George has to push in order to prevent the crate from moving.



10.4 George exerts a (greater/lesser) ____________ on the crate than Isaac.

10.5 George exerts a (greater/lesser) ____________ on the crate than Marie.

In Text 2, the section on force ends with 7 questions. Three of these are application type questions such as "How is lightening formed?" (p. 144). The four other questions are knowledge type questions, such as "Identify three types of contact forces" (p. 144). In both texts, then, questions are at a predominantly recall level, requiring no higher cognitive functions to act on them. The development of critical thinking and the ability to problem solve in the real world, and indeed in the science classroom, requires a higher level of cognitive engagement than the use of recall-type questions that rely solely on memory and could be acquired through rote, without much understanding involved in their acquisition.

In summary, our findings indicate evidence of some simple scientific concepts in Text 1 and none in Text 2. Most concepts analysed are at the level of simple scientific concepts that require teacher elaboration and that can lead, potentially, to misunderstandings if a teacher lacks the depth of scientific knowledge required.

Implications for practice and future research

Our findings pose a challenge in that most of the concepts analysed are at the level of simple scientific concepts: potentially simple science concepts require the teacher to add knowledge that lies outside the textbook. In a country in which science content knowledge is notably lacking among some teachers (Spaull, 2015) presenting apparently simple scientific concepts in textbooks poses challenges to learning. A teacher's ability to teach in this context is hampered by a textbook that is not sufficiently elaborated. The response to this requires the development of textbooks that provide explicit access to concepts in science. This finding adds to the body of work that analyses textbooks in a novel way in that it uses a categorical framework, developed out of the work of cultural-historical theory, to analyse the level at which concepts are presented for acquisition in science textbooks. We offer a brief caveat though; this is a small-scale study, and results should not be generalised outside of these specific texts. More research is required to ascertain whether this is a pattern in science textbooks in South Africa.

Conclusion

Crucial to learning science is a teacher who has good content knowledge of the subject. Evidence from South Africa suggests that this is not the case in many of our classrooms (Hardman, 2022; Hoadley, 2017; Spaull, 2015). Teaching science requires teachers to have access to excellent textbooks in which the science concepts are detailed and elaborated in ways that students can engage meaningfully with them. The selection of which textbook to use in one's class is of paramount importance but is dependent on the selection provided by the Department of Basic Education, so teachers have limited choice in which books to use. Using the work of Morris et al. (2016) premised on the work of Davydov (1991) and Vygotsky (1986), we analysed two popular, prescribed science textbooks used in grade 9 classrooms in South Africa. We selected only a single topic—*force*—to determine in an analysis of two texts how this scientific concept is presented. Our focus on *force*, of course, means that this represents merely a segment of the textbook and should not be generalised across other sections in the absence of further analysis. However, this analysis provides insight into content clarity, precision, and accuracy and maps out how these texts deal with concepts. *Force* is described in simple everyday language, with attached visuals and examples, and develops gradually into a concept of specialised scientific knowledge in Text 1 and potential scientific concepts (concepts that can be developed into full scientific concepts through interpenetration with the everyday concept) in Text 2. Although some explanations in the texts provide unambiguous meanings and promote intuitive understanding, others, specifically in the introductory sections of both texts, could pose challenges to learners since these concepts are merely potentially simple science concepts and require explication from the teacher for acquisition.

The exercises used to test learners' knowledge at the end of the unit are predominantly recall, knowledge-type questions that do not promote the use of abstraction or understanding but, instead, make use only of memory. When one is teaching abstract concepts such as *force*, pedagogical effectiveness and scientific accuracy must work together to promote learner's cognitive development. When teachers are left to elaborate on potentially simple scientific concepts outside of the text they have to use, they require good content knowledge in this field. Evidence from South Africa suggests that this is a challenge, and, therefore, we suggest that textbooks be designed with very explicit pathways towards concept development built into them. Developing learners' understanding further requires that the types of test questions given to them go well beyond mere recall and require analysis, synthesis, and evaluation to enable learners to demonstrate that they understand the concepts and are not merely relying on recall to answer questions.

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