USING EMBODIED EXPERIENCES FOR SCIENCE LEARNING:

A COGNITIVE LINGUISTICS INVESTIGATION OF STUDENTS’ METAPHORS IN CHINESE PRIMARY SCHOOL

by

Xinnan Kuai

A thesis submitted to the University of Birmingham for the degree of

DOCTOR OF PHILOSOPHY

Department of Education and Social Justice
School of Education
College of Social Science
University of Birmingham
August 2024

UNIVERSITY OF
BIRMINGHAM

University of Birmingham Research Archive

e-theses repository

This unpublished thesis/dissertation is copyright of the author and/or third parties. The intellectual property rights of the author or third parties in respect of this work are as defined by The Copyright Designs and Patents Act 1988 or as modified by any successor legislation.

Any use made of information contained in this thesis/dissertation must be in accordance with that legislation and must be properly acknowledged. Further distribution or reproduction in any format is prohibited without the permission of the copyright holder.

ABSTRACT

With increasing theoretical and empirical findings showing the importance of sensorimotor experiences on cognitive processes, science education research has begun to explore the effective use of bodily experiences in teaching and learning. In line with this argument, the embodied education approach, which refers to the active use of embodied experiences during the learning process, has been demonstrated effective in promoting students' understanding of science concepts by involving their bodily experiences. Although studies in embodied experiences have started to explore students' understanding of the concepts when physical experiences are involved in the learning process, it is perhaps surprising that little work has been carried out concerning how to integrate students' everyday embodied experiences. Also, there seems to be little published work that has investigated the relationship between embodiment and context in students' conceptualisation process.

Following these arguments, this research aims to investigate the impact of embodied experiences and context on science learning, mainly focusing on how it relates to students' understanding of scientific concepts. The present study adopted a mixed-method research paradigm, and the investigation was conducted through an elicit metaphor analysis approach. A total of 480 Chinese primary school students aged between 9 and 14 years participated in this study. They were asked to create metaphors in the X is Y format (e.g., "Gravity is...because...") by completing a designed paper-pencil-based questionnaire. A total of 145 students volunteered to participate in follow-up interviews, during which they shared their thought processes while completing the questionnaire. By examining students' metaphorical conceptualisations of selected concepts and their follow-up interview, the hope was that the results would not only shed light on how students developed their conceptual understanding through their everyday embodied experiences and situated sociocultural context but also how these two factors interplay during this process. In addition, the study aimed to understand students’ metaphor use for scientific concepts and how it connected with their level of conceptual understanding.

The analysis suggests that embodied experience plays an important role in constructing and expressing conceptual understanding. Moreover, students’ conceptual understanding of scientific concepts is also associated with family, school, and internet contexts, which contain numerous symbols that can serve as expressions of conceptual understanding; however, they may also give rise to misconceptions. Both embodied experiences and sociocultural context can serve as cultural tools, becoming significant resources for conceptual understanding. For metaphor use, different types of metaphors can be used to describe various levels of conceptual understanding, but the types of metaphors used for concrete and abstract concepts differ due to their varying relationships with embodied experiences. Additionally, universal metaphors are more often associated with misconceptions.

These findings highlight the importance of addressing specific challenges in science education in China by expanding embodied experiences, emphasising local context, and utilising diverse metaphors. This approach also offers insights for other regions facing similar issues, suggesting ways to tailor science education to their unique background. Additionally, this study introduces metaphor analysis as a research method for examining embodied experiences and context, providing a valuable example for research in this area.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

TABLES

FIGURES

GLOSSARY

1. **Classical Theory of Concepts**: The classical theory of concepts posits that a concept is a summary representation of a set of things based on conditions that are singly necessary and jointly sufficient for determining membership in that set (Fox, 2011). This theory suggests that concepts can be defined by specific conditions that are essential for categorizing objects or ideas.

2. **Conceptual Understanding**: Conceptual Understanding is used in a broad sense, as a single representation of a person's mental activities of scientific concepts, such as beliefs, concepts, and understanding (De Guerrero and Villamil, 2002).

3. **Domain**: Domain refers to the ideas or semantic field referred to by a lexical item. According to Cameron (2003), a domain is not just a collection of concepts or entities, visualized as nodes that can be labelled nominally, but also the relations between the entities—relations of cause and effect, composition, contrasts, etc.

4. **Elicited Metaphor**: Elicited Metaphor is used to indicate a specific type of metaphorical linguistic expression, in which a participant is asked to complete a metaphor-like prompt such as *Gravity is like* _____.

5. **Embodied Cognition**: Embodied cognition broadly refers to the processes of thinking, knowing and communicating that rely in some way on embodiment. Embodied cognition describes cognitive processes that deeply rely on features of the physical body beyond the brain (Shapiro, 2019).

6. **Embodied Experience**: Embodied experience refers to the way individuals perceive and interact with their own bodies and the world around them. It involves a deep connection between physical sensations, emotions, and cognitive processes (Shapiro, 2019).

7. **Embodiment**: Embodiment is a fundamental aspect of lived experience, and the study of embodiment builds on the basic view that our knowledge of the world is inseparable from our experiences of the bodies that we are. (Popova and Rączaszek-Leonardi, 2020).

8. **Extrinsic Property**: Construct with intrinsic property, extrinsic property is a characteristic that dependent on external factors or relationships with other entities

9. **Intrinsic Property**: An intrinsic property is a characteristic that an object or entity possesses based on its internal qualities or nature, rather than being dependent on

external factors or relationships with other entities (Marshall, 2021). Intrinsic properties are defined by the entity itself, rather than its relationship with external elements (Francescotti, 1999).

10. **Mapping**: Mapping is the process of making relational connections (also called correspondences) between objects in a source domain and objects in a target domain.

11. **Metaphor**: Metaphor in the cognitive linguistic view is defined as a specific example of a mapping between a source and a target domain (also called conceptual metaphor), in which the target domain is understood in terms of the source domain. (Kövecses, 2010).

12. **Misconceptions**: Misconceptions are inaccurate ideas or beliefs that individuals hold, which can either predate or emerge from instruction (Crowther and Knight, 2023).

13. **Moderate Embodied Cognition**: Moderate embodied cognition recognises the impact of sensorimotor processes on cognitive functions while remaining compatible with cognitivism. It emphasises the body's role in supporting the computational circuits underlying cognition (Kiverstein, 2012).

14. **Prototype View of Concepts**: The prototype view of concepts posits that concepts are represented by prototypes, which are abstract embodiments of the quintessential characteristics of a category (Gabora and Aerts, 2002). In this perspective, concepts are not strictly defined by necessary and sufficient conditions but are based on characteristic features that are weighted in the definition of the prototype (Cambouropoulos, 2001).

15. **Radical Embodied Cognition**: Radical embodied cognition posits that the human body itself constitutes a cognitive process, challenging traditional views by emphasizing the intricate link between cognition and bodily interactions with the environment (Raab and Araújo, 2019). This perspective rejects the need for mental representations and computational processes in cognitive activity, highlighting that cognition is situated within the dynamic system of the brain-body-environment (Beckes et al., 2015).

16. **Source Domain**: The source domain of a metaphor represents a concrete, relatively familiar, or relatively well-known entity. It is often used as one kind of evidence for the existence of conceptual metaphor, for example, "money" in "Time is money" (Kövecses, 2010).

17. **Target Domain**: The source domain of a metaphor means an abstract, relatively unfamiliar, or relatively unknown object. The target domain is the domain that people try to understand through the use of the source domain, for example, “time” in “Time is money” (Kövecses, 2010).

ACKNOWLEDGEMENT

This PhD journey has been an incredible experience, and I am grateful to all the individuals who have supported and guided me along the way. Reflecting on these past four years, I realise how fortunate I have been to receive support from so many wonderful people.

First, I would like to thank my two supervisors, Dr Tonie Stolberg and Dr Donna Dawkins. For the last four years, Tonie never hesitated to provide me the valuable guidance whenever I was confused. This helps me to lay a solid foundation for my future academic life. I still remember our first meeting when Tonie mentioned how he would be the ‘mother figure’ during my PhD, and it was this support that helped me get through these four years. My second supervisor Donna can always understand my ideas and feelings. She can always think from my perspective and provides the exact support, whether in academics or future development aspect. I felt endless warmth from her, encouraging me to keep improving.

I also want to extend my sincere thanks to my family. Especially my mom, who gave me all of the care she could throughout my PhD studies, and my husband, who has always treated my matters as his own and been my most solid emotional support. I am also grateful for the company of my three cats, Jiujiu, Tangtang, and Guoguo, who have been with me every writing night.

Additionally, thanks to my sample school and its staff for allowing me to collect data, and to Yaling Hsiao for providing me with opportunities to practice my higher education teaching skills. This journey would not have been possible without your assistance.

Completing my PhD journey is not an end but a new beginning. There are more paths ahead for me to explore, and I am excited about the future.

AUTHOR'S DECLARATION

I declare that all the work presented in this thesis is original and based on my own work, and I understand that my thesis may be made electronically available to the public.

1 INTRODUCTION

This chapter provides an overview of this research investigating how embodied experiences and students' sociocultural contexts impact their understanding of scientific concepts. It begins with the study's background, and current gaps in this field, followed by the guiding research aim and an overview of the research methodology. Additionally, it includes a statement of my positionality, explaining my personal and professional background related to the study's topic.

1.1 Background and Rationale

Scientific concepts serve as essential building blocks that enable students to comprehend and analyse complex scientific phenomena (Duit and Treagust, 2003). Learning scientific concepts is paramount in science education as it underpins students' scientific literacy, understanding of the nature of science, and ability to make informed decisions (Amala et al., 2023), all important for science education. Recent years have seen a shift in science teaching, moving from emphasising students' mastery of discrete science content to engaging them in the processes of science and engineering (Lee et al., 2020). Students in science classes are now expected to construct explanations for phenomena, develop models, and argue their claims from evidence (National Research Council, 2012). This necessitates students' deeper understanding of scientific concepts.

In the realm of scientific conceptual understanding, embodied cognition proposes that sensory and motor experiences play a crucial role in how individuals perceive and understand abstract ideas (Glenberg, 2015). What we usually view as a simple notion—the body—opens to a multitude of theoretical perspectives that build on different traditions and premises about science learning (Amin, 2015; Niebert et al., 2012). This theory highlights the connection between sensory experiences, motor actions, and cognitive processes, suggesting that cognitive functions are not solely brain-based but are influenced by bodily interactions with the environment (Buxbaum and Kalénine, 2010). Through engaging with the environment via sensory and motor interactions, individuals can develop a more comprehensive understanding of scientific concepts (Schuman-Olivier et al., 2020). Researchers argue that thinking about and understanding science needs embodiment both in concrete and abstract learning domains (Niebert et al., 2012). To make sense of these concepts, we project patterns of sensorimotor experiences onto more abstract domains, and everyday language reflects these projections (Lakoff and Johnson, 1980c).

Recently, a new perspective has emerged which is concerned with extending the embodiment into its context since embodied experiences are developed by the interaction between humans and the environment (Dewey, 1958). Ramstead et al. (2016) highlight the interaction between culture, context, and biology in shaping human behaviour and cognition. Oliveira et al. (2023) further elaborate on the theoretical development of psychological phenomena within the framework of

Embodied and Enactive Cognitive Science, emphasising the emergence of cognitive processes from interactions between embodied experiences and sociocultural contexts. Moreover, as a continuing critical topic in science education, the sociocultural context itself already plays an essential role in science education. These arguments suggest that the investigation of embodied experiences should also include their situated sociocultural context, which shapes how individuals perceive, interact with, and make sense of their environment, especially for research in the science education field.

The above discussion emphasises the importance of conceptual understanding in science education and its relationship with embodied experience and sociocultural context. Following these arguments, this research aims to investigate the impact of embodied experiences and context on science learning, mainly focusing on how it relates to students' conceptual understanding of scientific concepts.

1.2 Research Gaps and Research Questions

The previous section mentioned that embodiment and the associated emphasis on context have generated many new perspectives in science education. These studies have introduced significant new value, yet some issues remain unresolved.

Firstly, there is no consensus on how to define embodiment in science education. While a greater focus on the body promises to provide a more holistic account of scientific meaning-making processes, research on embodiment in science education is still an emerging field and far from established. Consequently, considerable theoretical and methodological differences persist within the research on embodiment in science education, hampering productive discourse around the topic (Kersting et al., 2021). While science educators have started to acknowledge the critical role of the body in science learning, approaches to conceptualising the body in science education vary greatly. For this issue, it is argued that despite the many merits of looking at embodied ways of learning, there is no one best way to think about the role of the body in science education (Alsop, 2011). This research aims to examine the specific embodied experiences related to the conceptualisation of scientific concepts.

Second, the main focus in the above theories of embodied cognition has been on the relation between the individual body and its cognitive processes in interaction with the material environment. However, for humans, living in the world is not an individual enterprise because the world comprises social and cultural contexts (Lindblom, 2007). Actions have social meaning, and agency takes place within a web of cultural structures (Anderson, 2003). As such, researchers have made calls to move beyond the traditional emphasis on interactions between the individual and the physical environment to encompass embodied interactions between embodied agents in their social environments (Johnson and Rohrer, 2007). Currently, there is a lack of empirical research in this field. This study aims to provide more empirical evidence of how embodied experience and sociocultural context interact with each other, especially when constructing interpretations of scientific concepts.

Moreover, although embodied learning may play a role in all learning, not all learning environments are intentionally developed to leverage embodied learning. For example, students discussing particles in motion may use the areas of their brain related to movement to understand that idea. Therefore, in addition to the current trend in embodied science education, which emphasises using students' bodies move actively in learning (Johnson-Glenberg and Megowan-Romanowicz, 2017), it is equally important to consider how to utilise students' embodied experiences in their daily lives for the learning of scientific concepts. This study will thus focus on how students' embodied experiences in their daily lives and their situated sociocultural contexts influence their conceptual understanding.

Therefore, to contribute to the research gap mentioned above, the present study adopted an exploratory stance, taking Chinese primary school students as participants and exploring their conceptualisations of selected scientific concepts. The main research question is to explore: *How are students' understandings of scientific concepts related to their embodied experiences and sociocultural context*? Through this main research question, this study specifically focuses on what embodied experiences students use to interpret scientific concepts as well as how this process relates to students’ sociocultural context. It will also explore how these embodied experiences and sociocultural context impact students’ conceptual understanding, particularly in the everyday context.

1.3 Research Design and Methodology

In order to conduct the investigation of conceptual understanding, embodiment, and sociocultural context, metaphor could be used as a valuable tool. According to the conceptual metaphor theory (Lakoff and Johnson, 1980a), metaphor is not only a language phenomenon but also a conducive instrument for constructing an understanding of abstract concepts, and many scientific concepts are constructed based on metaphors. It is possible for researchers to analyse conceptual understanding of scientific concepts through metaphors (Wan and Low, 2015). Moreover, the metaphor emergence in this process is based on concrete physical experiences and their context (Kövecses, 2020). This means that metaphor can not only reflect scientific understanding but can also connect with embodiment and context, linked with the main topic of this research.

A review of the literature reveals that over the last few decades there has developed a heightened awareness of the importance of metaphors as a tool for uncovering participants’ conceptualisations in the education area. Both Cognitive Metaphor Theory (Lakoff and Johnson, 1980b) and Vygotskyan notions of the interactive nature of language (i.e., metaphor) and thought (Vygotsky and Cole, 1978) within Sociocultural Theory suggest that metaphor can be treated as a mediational tool, whereby the researchers’ interpretations of informants’ thinking and understanding are constructed from accounts given by them in specific social environments. Informants’ metaphors have accordingly been utilised for reflection and consciousness raising among students and teachers, to shape their classroom practices (Tobin, 1990), to mediate understanding of their beliefs about teaching (and learning) in the classroom and ultimately to predict behaviours likely to follow on from them (Wan et al., 2011).

Quite a high proportion of these studies have collected informants’ narratives by completing researcher-constructed prompts involving part of a metaphor or simile in X is (like) Y format; for instance, “Learning is (like)...”. Some studies (Jin and Cortazzi, 2011; Saban et al., 2007) further ask respondents to justify their metaphorical reasoning (i.e., X is (like) Y because...) in order to try to interpret the (metaphorical) language in terms of their personal thinking or beliefs. The use of such a metaphor elicitation technique to analyse beliefs is not recent. The last fifteen years have seen the publication of a series of studies examining both teachers’ and students’ understandings of teaching and/or learning through various metaphor elicitation tasks (Cortazzi and Jin, 1999; Tramowsky et al., 2022; Zapata and Lacorte, 2007), based on the idea that identifying and discussing metaphors can bring implicit assumptions into awareness, or encourage personal reflection, and as a result provide some insights into individuals' perspectives on given topics (Cameron and Maslen, 2010).

Since the current study aimed to explore Chinese primary school students' beliefs and understandings relating to scientific concepts, it required an in-depth investigation of their conceptual understanding. Therefore, it would be more useful in the present study to adopt a qualitative research paradigm as its theoretical and philosophical orientation (Creswell, 2011). Participants in this research were asked to (a) provide metaphors of scientific concepts in the X is like Y format (e.g., Gravity is like a stone) and (b) share their rationale for their metaphor generation through 'because' (e.g., Gravity is like stone, because it is heavy). To reduce the incidence of unsuccessful answers to the metaphor elicitation task, all participants were also asked to attend a 20-minute training programme before creating metaphors. Follow-up interviews were also conducted to further investigate this process. Through analysing these metaphors and interview transcripts, except for investigating the main research question, this study also aimed to review how students' conceptual understanding related to their metaphor use, and the methodological challenges of employing elicited metaphor analysis approach for investigating students' understanding in the science education field.

1.4 Positionality Statement

As a researcher with a background in science education in China, my positionality significantly shapes the lens through which I approached this study.

My motivation for conducting this research is based on my educational and professional experiences. My educational journey in China as a student was marked by a strong emphasis on rote learning and high-stakes examinations. While this system fostered discipline and rigorous study habits, it often left little room for experiential learning and critical thinking, aspects I found crucial during my subsequent teaching career since many students tell me they feel the knowledge they learn is separated from their daily life. These experiences drive my curiosity about how embodied experiences—students' physical interactions and cultural contexts—affect their grasp of scientific concepts, which are often taught in abstract and decontextualised ways.

Growing up and completing my science education in China, I experienced first-hand the unique educational practices and cultural contexts that shape students' understanding of science. My subsequent professional experience as a primary school physics teacher further solidified my interest in exploring how Chinese students learn science. These experiences make me an insider within the Chinese educational system, and a deep understanding of the cultural nuances and pedagogical practices that influence student learning. This insider perspective allows me to relate closely to the participants and understand their experiences on a profound level. In this study, I am committed to bridging the gap between students' everyday experiences and science learning. By drawing on my own experiences and engaging empathetically with participants, I strive to ensure that their voices and perspectives are authentically represented. I aim to remain transparent about my positionality throughout the research process, acknowledging how my background might influence the study's findings and interpretations.

However, I am acutely aware that my personal biases, shaped by my educational background and teaching experiences, might influence my data interpretation. To address this, I maintain a reflexive stance, constantly questioning my assumptions and remaining open to diverse perspectives. To mitigate potential biases, I have sought feedback from colleagues and supervisors and engaged with a diverse group of informants to gain a comprehensive understanding of the research context. This approach not only enriches the study but also ensures that my findings are robust and reflective of the complex realities of Chinese students' science learning experiences.

In summary, my positionality as a Chinese researcher and former physics teacher deeply informs my study. My personal and professional experiences provide me with motivation and valuable insights, yet necessitate a conscious effort to maintain reflexivity and critical examination throughout the research process. This balance allows me to contribute authentically to understanding how culture and embodied experiences shape scientific learning among Chinese students.

1.5 Thesis Structure

This thesis is comprised of six chapters.

The present chapter outlines the motivation for the study, research aims and significance, and the research questions. The remainder of the thesis is organised as follows:

Chapter 2 reviews the existing research in the fields of embodied cognition, Chinese science education, and conceptual understanding in science education. It also provides the theoretical framework and specific research questions of this study.

Chapter 3 details the research design and methodology for collecting participants' metaphors of scientific concepts, their reactions to the metaphor training sessions, and their follow-up interviews. The mixed method research approach used in the main study is outlined and justified.

Chapter 4 synthesises the findings of participants' metaphors of scientific concepts and the analysis results of follow-up interviews.

Chapter 5 presents the discussion of findings from Chapter 4 and summarises the main findings of the study, answering the main and sub-research questions.

Chapter 6 discusses the study's contributions, implications, applications, and limitations, and suggests areas for future research.

2 LITERATURE REVIEW

Understanding the fundamental mechanisms underlying advanced cognition offers educators an important perspective for promoting the learning process. New theories on learning and cognition developed from a diverse array of fields such as philosophy, psychology, linguistics, neuroscience, and computer science, are now being incorporated into the area of learning science, which generates fresh insights into the education theoretical developments of education.

This chapter begins by outlining the current advancements in the field of cognition, with a focus on the diverse theories of embodied cognition. It also examines the role of sociocultural context within this domain. Then it will discuss the distinctive characteristics and particular contexts of science education in China, illustrating how to combine the cognition theory into this specific context. Subsequent sections delve into crucial aspects of learning scientific concepts and present which aspects of conceptual understanding this research focuses on. The chapter ends by introducing Conceptual Metaphor Theory, discussing its capacity to synthesise embodiment, context, and cognition, and establishing it as the foundational theoretical framework for this research.

2.1 Embodiment, Sociocultural Context, and Science Learning

As recognition of the extraordinary influence of action on learning grows to in extent, traditional cognitivist accounts of learning have been challenged by research findings from various discipline areas since they exclude showing the profound relationship existing between mind and body (Kontra et al., 2012). This chapter is centred on exploring the intricate relationship between embodiment and the sociocultural context, along with their application in the domain of science education.

It delves into this discussion by first introducing, in Section 2.1.1, a comprehensive description of the concept of embodied cognition. This includes tracing its origins from the foundational cognitive theory and delineating its bifurcation into two distinct sub-perspectives. Subsequently, Section 2.1.2 elucidates the significant role that context plays within the framework of embodied cognition. Advancing the discourse, Sections 2.1.3 and 2.1.4 present a critical review of how these cognitive theories are currently utilised in science education, highlighting certain transformations that have occurred and pinpointing specific areas that require deeper exploration and research.

2.1.1 Standard Cognition, Moderate and Radical Embodied Cognition

Since the mid-1980s, the concept of embodiment has been extensively used in cognitive science and AI literature. (Ziemke, 2003). With its development, the notion of embodied cognition is far from uniform as it has been developed in many different research areas and has many different yet related meanings (Zwaan, 2021). Different types and notions of embodiment can be seen in a variety of related terms such as cognitive embodiment, phenomenal embodiment, social embodiment, and even embodiment from a historical, physical, and organismic perspective. To help navigate these diverse arguments and construct the definition of embodiment within my research, this section will present and compare various arguments and introduce two dominant perspectives within the field of embodied cognition.

Embodiment was first defined in cognitive science as a response to traditional cognitive science. It offers an alternative perspective, challenging the standard view that mental processes are decontextualised symbolic operations, and is seen as an evolutionary step forward in understanding these processes (Anderson, 2003). The standard version of cognitive science has roots in various disciplines such as computer science, psychology, and linguistics. The domain is relatively clearly circumscribed, including cognitive process perception, memory, attention, language, problem-solving, learning, and so on. It adopts a computational theory of mind, according to which cognitive processes are as same as the processes occurring within a computer (Shapiro and Stolz, 2019). The mental process, from its point of view, proceeds algorithmically and operates on a number of symbolic representations. Cognitive tasks start with specific symbolic inputs and end with an output from the brain, limiting the cognitive process only within our brain. Standard cognitive science, in line with its ontological perspective, usually limits its investigations to cognition within the brain, disregarding the external world. Additionally, it prefers to employ standardized methodological practices, such as reaction time experiments, recall tasks, and dishabituation paradigms, to reveal features of mental algorithmic processes and representations (Shapiro, 2019).

One of the typical empirical investigations in standard cognitive science is Newell and Simon's General Problem Solver (Newell and Simon, 1972). Newell and Simon developed a computer program called General Problem Solver (GPS) to solve logic problems similarly to how a human would. Their goal was to replicate the mental processes humans use in solving logical problems, which suggested the hypothesis that cognitive processes are akin to computational processes.

Standard cognitive science has been dominant for quite some time and is proven to be able to address certain cognitive activities. But this view has also received many challenges. On the one hand, there is no solid empirical case that supports the existence of amodal symbols in the brain (Niedenthal et al., 2005). On the other hand, many psychological events still fall outside the range of computational interpretation and could not be explained by this orthodox conception of cognitive science, and its Cartesian ontological dualism has also been challenged by many researchers from the philosophy area (Fodor, 1983).

At the same time, theoretical and empirical findings from cognitive neuroscience, psychology, and linguistics indicate that the effects of sensorimotor processes on mental processes are significant and cannot be ignored (Goldinger et al., 2016). A growing body of evidence that has revealed the role of factors other than the brain in cognition has led some cognitivists to set out to consider a new understanding of mental processes. Over the past two decades, the literature on embodied cognition has seen a notable increase (Raab and Araújo, 2019), indicating that it has transitioned from a fringe topic to a mainstream area in psychology (Zwaan, 2021). Embodiment has become a crucial concept in various aspects of cognitive science.

Although there are a series of versions of embodiment theory, for the most part, they are committed to the implementation of any human cognitive process is critically dependent on the availability of physical and bodily systems or organs, which is the uncontroversial part of embodiment theory (Convertini and Arcidiacono, 2021; Ionescu and Vasc, 2014). The controversial focus of the different theories in this field is on whether and to what extent the representation of nonneural bodily parts matters to human thoughts and higher cognitive tasks (Alsmith and Vignemont, 2012). As a response to this debate, there are two different standpoints in embodied cognition, with one a weak/simple/moderate version and the other a strong/radical version, which focuses on how the body impacts our cognition.

For the proponents of a moderate version of embodied cognition, even though there is a growing commitment to the opinion that the mind must be interpreted in the context of its relationship to a physical body situated in reality, they still consider that abstract representations take on a role in cognitive activity (Goldman, 2012). In this moderate version of embodied cognition theory, the role of the body is to support as well as constrain the mind biologically. Advocates of this perspective still affirm the existence of mental representations but pay more attention to the evolutionary and developmental roles of bodily experience. For high-level cognition, a moderate account is within the realm of inner representation and stresses the contribution of an agent’s mental representations of the body to higher cognitive processes (Jacob et al., 2016; Pouw et al., 2014).

For instance, Schulz et al. (2018) used mental representations to explain the decision-making process in sports and argued that the representational process is fast and frugal in this case. Regarding the explanation of abstract concepts, some researchers have begun to opt for weaker, pluralist versions of concept empiricism called symbol pluralism (Dove, 2009; Meteyard et al., 2012; Pulvermüller, 2013), which believes that a number of concepts require both modal and amodal symbols. However, this pluralism still inherits the problems of amodal symbols(Barsalou et al., 2008).

This moderate version of embodiment received some criticisms since it excludes the more substantial role of the body and environment within a cognitive process

(Joldersma, 2013). It is shown that the tradition of cognitive science that highlights the computational way of human thinking still shapes this perspective on embodiment. In this field, the body is one factor that contributes to the emergence of representations in the mind, rather than an independent factor that can impact cognition directly.

For radical embodied cognition, according to the classification by Shapiro (2019), this perspective focuses on the theory of replacement. Researchers in this field reject the existence of representations in the brain and argue that the computational approach in standard cognitive science is inadequate for studying cognition. They advocate for abandoning computationalism in favour of investigative tools that better accommodate the continuous nature of cognition. Researchers in this field adopt Maurice Merleau-Ponty's definition of the phenomenal body, which means that the body is an embodied subject exhibiting an intentional connection to the response by the solicitations of situations in the environment (Dreyfus, 2002). This radical intentionality embodiment supported is non-representational but instead correlated with Gibson's definition of affordances, which means the interacting embodied subject and environment based on particular bodily shapes and action potential (Gibson, 2014). It is the affordances that combine the bodily part of an organism and its situated environment.

Different from the moderate one, the radical theory of embodied cognition posits that the brain's primary function is to support active and meaningful bodily interactions with the world. The relationship among the brain, body, and environment is seen as modulating, dynamic, and adaptable, influenced by continuous contextual feedback. Sensorimotor bodily interactions are based on the general dynamic schema but are continually modulated by continuous sensory feedback emerging new ways of enacting the intentional schema (Raja, 2021). It is the coupling between the brain, body, and mind that consists of the higher cognition. The work of Brooks (1999) about artificial intelligence also represents a critical role towards radical embodied cognition. According to Brooks, when modelling intelligent behaviour, it is not correct to construct an explicit representation that represents all aspects of the world since it is not a unit of abstraction. Instead, intelligent behaviour uses the world as its own model and dynamically exploits an environment’s constraints. Some initial research performed on animals and humans that concentrated on the effects of the environment on their cognition and behaviour provided empirical evidence for this perspective (Held and Hein, 1958; Kirsh and Maglio, 1994).

One approach that addresses this issue is dynamical system theory. This theory suggests that perception can be understood in terms of affordances, or potential interactions with the environment. It originates from the ecological psychology proposed by Gibson (2014). This theory explains that, just as a governor’s causal circle in an engine includes elements like the throttle valve, flyball, and flywheel, the circle of causality for cognition includes the brain, body, and environment. Here, ‘embodiment’ emphasises the dynamic interaction between the brain and body. The term 'situated' refers to the idea that the body is positioned within and interacts dynamically with the environment. Thus, there is a coupling relationship between these three components, which explains the human cognitive process.

This dynamical system theory has been embraced by some researchers in the field of embodied cognition. In his continually cited article *six perspectives of embodied cognition*, Wilson (2002) emphasised that a key aspect of embodied cognition is its situational nature, the influence of time constraints, and the inclusion of the environment as an integral part of the cognitive system. This supports the main arguments of this approach. Smith and Thelen (2003) also affirmed the self-organizing ability of this dynamic system. Moreover, Beer (2014) suggests that dynamic accounts offer the potential for unification. By viewing the brain, body, and world as interconnected dynamical systems, it becomes possible to use the descriptive tools of dynamical systems theory to understand each component.

From this standpoint, it is evident that a significant distinction between moderate and radical views of embodiment lies in the role of the environment. According to the radical view of embodiment, the environment, which is the context that emerges at the moment, also plays a crucial role in cognition. Evidence has shown that even for abstract concepts, which do not entail motor interaction with the world, this radical dynamical coupling also contributes, and there is no representational detail of conceptual content stored for abstract thinking.

The range of environment, in the case of education, refers not only to the physical environment but also to the sociocultural context in which we are situated. We all live and grow up within larger-scale social organisations such as family, and schools which provide us tools for sense-making regarding the world around us. According to Lemke (2001), it is the combination of these tools, our social semiotic resources, and the culturally significant methods of using them that form the culture of a community. Along with this argument, the sociocultural context also cannot be ignored when investigating embodiment in educational research.

2.1.2 Embodied Experience and Sociocultural Context

Before the emergence of embodied theories that offered a cohesive framework, since 1980s, there had grown increasingly concerned with the academic research and writing focus on the role of social significance to the body (Shilling, 2016). Embodiment from this perspective, namely social embodiment, could be seen as an extension of the radical version of embodiment, which proposes that this cognitive process is situated in a broader sociocultural context. Leung et al. (2011) presented the theory of embodied cultural cognition, which is dedicated to theorising sociocultural variations in the embodiment. Cohen and Leung (2009) argue that the concept of embodied cultural cognition aligns with the idea of situated embodiment by highlighting the cultural affordances in the environment that give rise to specific embodied phenomena. They believe that research in this area represents a notable advancement from traditional embodied cognition studies.

Over the years, numerous research findings have accumulated that implicate embodiment in social and cultural cognition. Researchers from developmental psychology have demonstrated that infants' motor skills and subsequent developmental outcomes were profoundly influenced by the different historical and cultural child-rearing practices. This is because caregivers usually support and constrain motor behaviour by structuring the physical environment, which makes the movement of infants embodied and embedded (Adolph and Hoch, 2019). Niedenthal and colleagues (2005) demonstrated that embodiment is essential for social information processing in both online cognition, which involves engaging with real social objects, and offline cognition, which involves imagining social objects when they are not present. Morrissey and his team analysed variations in finger-counting patterns among university students across different cultures and within the same culture. They developed a motor simulation theory of embodied numeracy, suggesting that our finger-counting habits partly shape how we manipulate symbolic numbers.

This version of embodiment alongside associated interests in the social and cultural effects, has been a significant development in recent decades (Shilling, 2016). On the one hand, the insights provided by embodied approaches have enhanced existing understandings of social phenomena like social judgment (Meier et al., 2012). On the other hand, Schubert and Semin (2009) argue that recognising the situated nature of social cognition within sociocultural contexts, especially in social psychology, can further advance psychological theories and research in embodied cognition by offering a unifying perspective (Leung et al., 2011a). The establishment of the interdisciplinary field would also further facilitate the collaborative work between social psychology, cognitive science neuroscience, cognitive linguistics, and other disciplines, which will hopefully provide meaningful contributions to our understanding of the human cognitive process.

These results emphasise the significance of the sociocultural context in shaping both embodied experience and human cognition. The context plays an indispensable role, relevant to research in both embodied cognition and cognitive science more generally. This is also in agreement with the radical embodiment perspective, which particularly highlights the influence of the environment.

2.1.3 Embodied Cognition in Science Education Research

With its development, embodied cognition theory has been proven strongly correlated with and has the power to respond to issues within the education field. A number of research findings have elaborated that appropriate sensory-motor experiences are necessary for promoting educational practices, which leads to a renewed and more nuanced understanding of learning as an embodied process (Gulliksen, 2017). Embodied learning, discussed in the previous section as an application of embodied cognition theory, represents a modern pedagogy of learning. It is currently seen as one of the most innovative and crucial approaches in education (Georgiou and Ioannou, 2019).

In their seminal article, Nguyen and Larson (2015) presented three categories of subject matters applied in embodied cognition. The first kind of subject has an inner physicality through focusing on the body or learning manual skills, such as kinesiology, disciplines based on hand on activities, and mechanics. The second category includes the subject matter based on socially based classroom performance. For the third category, which includes disciplines concerning spatial subject matter in their concepts such as mathematics or science, Nguyen and Larson argue that it presents the greatest challenges among these three subject matters since much of the important knowledge in these fields is relatively abstract. The abstract way of teaching concepts in this field leads to the disconnection between knowledge and students' experience in the world since the knowledge is stored in memory as an abstract symbolic form. It makes students find it challenging to apply knowledge in this field to their everyday lives (Leitan and Chaffey, 2014). However, it has been proposed that even for abstract science disciplines like science, fundamental concepts are also connected with the embodied nature of the human mind (Sung et al., 2017).

The embodied learning method now has been applied to many disciplines, such as areas like sports, language, and STEM (science, technology, engineering, and mathematics) education. This approach is believed to have the potential to lead learners toward these disciplinary perspectives (Abrahamson and Lindgren, 2014).

In the field of embodied science education, one of the most important methods in this area is enhancing science learning by integrating embodied experiences in science studies. After embodied cognition proposed the relationship between the advanced cognitive process and the human sensorimotor system, more and more educational scholars have begun to investigate the use of this theory to enhance students' learning of scientific concepts. Meanwhile, with the emergence of various accessible motion-based educational technologies, it provides new perspectives for the design of technology enhanced embodied curriculum design and a series of embodied technological practices in science education, which can offer students the chance to integrate their bodies in the learning process to varying degrees (Georgiou and Ioannou, 2019).

Most of the researchers in this trend of study have devoted themselves to creating a virtual learning environment or augmenting some component of reality through mixed reality or virtual reality technology. This type of research is most prominent in the series of studies conducted by (Lindgren et al., 2016). In 2016, Lindgren and his colleagues presented 58 middle school students with an immersive, whole-body interactive simulation learning environment for the study of Gravity and planetary motion. After comparing their FCI (Force Concept Inventory) questions results and attitude about science learning with students who used a desktop version of the same simulation, it was indicated that students’ understanding of target physics concepts is different due to varying degrees of body engagement. It is proved by the empirical research in 2017 that if scientific knowledge was tested by the approach that facilitates gesture usage, participants’ scores were significantly higher (Johnson-Glenberg and Megowan-Romanowicz, 2017). Other similar technology enhanced embodied science learning approaches, such as haptic feedback (Schönborn et al., 2011), and object manipulation (Convertini and Arcidiacono, 2021; Merkouris et al., 2019), have also been proven effective in promoting students’ concept understanding through integrating embodiment with science learning. It is supported that the level of body engagement during the learning process has been evidenced to be inseparable from the way we perceive scientific concepts.

Within this field, it has been argued that different technologies would bring different levels of embodied experience to students and also have their own impact on the effectiveness of science learning. Ioannou et al. (2019) designed two different embodied courses to teach 4th-12th grade students about nutrition and healthy food choices in an authentic classroom setting. In their work, one group of students received a high-embodied, Kinect-based educational game, and another was provided with a low-embodied, which was supported by a desktop providing same game for comparison purposes. Findings concluded that compared to the low-embodied group, students in the high-embodied group performed higher learning gains and a more constructive view of technology integration. This result corresponds with the work of Lindgren et al. in 2016, which demonstrated that an immersive, whole-body interactive simulation is more effective than a desktop version of the same simulation. It is suggesting that the level of bodily engagement is critical to the approach of technology enhanced embodied science design. Moreover, results from this research further substantiate the engagement of the environment in cognitive processes, affirming that the body is not the sole component of cognition.

Integrating real-time embodied experiences provided by various methods into science learning has been proven beneficial for scientific education. However, it has been questioned whether the effort and development costs of reality reproduction are worthwhile (Lindgren and Johnson-Glenberg, 2013). This is because from the perspective of embodied cognition, the foundation of students' understanding of scientific concepts is their own bodies. It is our body that decides the interpretation of the surrounding world, which is the basis for emergence of conceptual understanding. The role of the body is not limited to science classroom learning but occurs in daily life as well. It is these shared embodied experiences that facilitate our understanding of scientific concepts, and this research trend has only addressed one aspect of it.

The cognitive offloading method is one of the typical examples of this trend that aims to help us overcome these capacity limitations and minimize computational effort. It shows how we can take advantage of our bodies and entities in the outside world as a teaching and learning strategy to assist people in thinking. Based on a radical and dynamic version of embodied cognition theory mentioned in Section 2.1.1, there is a dynamic coupling between mind, body, and environment within the cognitive process. Modifying any one of the three factors will have an impact on the other two and the final outcome. Therefore, the impact, as well as limitations of a human’s living body and the environment it is situated in, is essential for the cognitive offloading method (Choi et al., 2020). The coupling between mind, body, and environment offers offloading cognition a crucial function that is able to offload the information processing requirements and cognitive demand for a task. It enables cognitive outcomes that would be impossible to achieve by other means, and this approach has affirmed its contribution to cognition across several domains (Risko et al., 2014).

In science education, the cognitive offloading method used in embodied science education can be broadly categorised into actions that transfer cognitive demands onto the body and those that transfer them into the world. The research about offloading cognition onto the body focuses on how to use our bodies actively to minimise the demand of cognitive ability for science learning. For instance, when 11 kindergarten students were learning about shadow formation, Herakleioti and Pantidos (2016) led students to actively employ their own bodies as obstacles to explore the direction as well as relative positions of the light. In addition to the positive impact on students' conceptual understanding, students' bodies could also support the transformation of embodied knowledge into different settings. Another example of using students' own bodies in learning science concepts is the Drama-in-Education approach, which incorporates mine or extended role plays and simulations of social events. Through these activities, students' visualisation skills were developed through embodied sensation as well as anthropomorphic metaphors (Dorion, 2009). Academic research in this field has been proven successful in facilitating students' interpretation of scientific concepts.

Another significant example of the cognitive offloading method is the integration with gestures. In 2017, Johnson-Glenberg and Megowan-Romanowicz (2017) assessed the learning gains of undergraduate students after a one-hour lesson on the electric field. In their research, one assessment is a traditional text-based physics test accomplished by using keyboards, and another one is a more embodied, transfer test in which students were able to use the Wacom large tablet allowing using gestures such as long swipes to generate concepts such as vectors and answers. The finding indicates that students in the two positively embodied groups showed better performance in both test scores and engagement. The use of gestures has the potential to reduce students' cognitive demands, thereby facilitating their science learning and becoming one of the most popular approaches for embodied science education. Another method, offloading cognition into the world, is also common in our everyday cognitive activities (Nestojko et al., 2013). Different from offloading cognition onto our body, this specific method uses objects in the external world as the repository of representational information such as a computer (Sparrow et al., 2011) or sketch (Tversky and Chou, 2011).

There are also many studies that align with radical embodied cognition, focusing on the importance of the environment in this field. It is shown that the method of whole-body engagement, such as a specially designed mixed reality environment, could promote science learning outcomes (Johnson-Glenberg and Megowan-Romanowicz, 2017). Han and his team (Han et al., 2017) created an enhanced haptic simulation that delivers both force and kinesthetics feedback via a commercially available force feedback joystick. This approach has been shown to be more effective than similar non-haptic simulations in offering embodied experiences and assisting elementary students in grasping physics concepts. The technology of an immersive virtual environment is also frequently used to facilitate cognitive processes (Fitton et al., 2020; Johnson-Glenberg, 2018). One of the most impactful theoretical frameworks consistent with the concept of embodied cognition is the Ecological Dynamics approach developed by Dor Abrahamson and his team. This approach seeks to understand how learning evolves from physical actions to conceptual understanding in STEM education (Abrahamson and Bakker, 2016). According to Abrahamson, embodied learning occurs when students address perceptual-motor coordination challenges, where they must synchronize their perception and physical movements to complete goal-directed tasks.

Above content presents a brief review of the current trends in embodied science education research. It is important to stress that these methods mentioned above are not separate from each other. Researchers sometimes integrate several methods together for embodied learning design. As an exemplification, Johnson-Glenberg (2018) designed research to offer embodied affordances by gestures in 3D for the learning of Coulomb’s Law. Many scientists have devoted themselves to applying embodied cognitive theory to promote students’ science learning through the combination of a variety of approaches. The above perspectives indicated that embodied experiences not only from the classroom or science lab but also from everyday life can have an impact on students’ conceptualisation of scientific concepts. No matter whether through mixed reality objects or daily material, the effect of embodied experiences on the learning process is achieved through providing or enriching various types of embodied source domains to understand science theories and concepts, further stressing its importance in science education. By stimulating or utilising students’ bodies during science learning by employing various approaches, embodied science education has been shown to have a positive impact on their understanding of scientific concepts. Moreover, researchers have also informed that students’ everyday physical experiences before the class regarding torque angular momentum could also facilitate their perception of target concepts (Kontra et al., 2015).

It has also been found that much of the research on the investigation of the body and conceptual understanding has been concentrated in physics, especially the mechanics section (Walsh et al., 2020). This is related to the characteristics of the physics discipline. Many scholars point to physics as a privileged domain, where children have access to rich experiences well before they enrol in school. Children have an intuitive understanding of objects from infancy, including their permanence and qualities. By kindergarten, these instincts had matured into a sophisticated sense of mechanical causation and an awareness of the connections between unseen causes and observed outcomes (Yoachim and Meltzoff, 2003). In their everyday life, students are also exposed to physics in a variety of settings. These all provided a rich resource for their conceptualisation of physics concepts.

However, incorporating embodiment into science education also presents several challenges. Firstly, many psychologists and learning scientists are concerned that technology-enhanced approaches in embodied science education might be perceived as mere superficial effects without substantial educational value (Goldinger et al., 2016). Currently, the evidence supporting the effectiveness of technology-enhanced embodied learning environments is limited and scattered (Malinverni and Pares, 2014). Consequently, the ongoing challenge is to integrate positive findings from empirical studies in this field to validate the effectiveness of technology-enhanced embodied education in science learning. As Johnson-Glenberg et al. (2014) have noted, there is an urgent need for a more sophisticated understanding of embodied learning design.

Secondly, the tradition of education practices also has an impact on the implementation of embodied science education, since learners' expectations have been shaped and socialised that learning spaces and instruction should direct their learning to their head instead of the entire body, which may cause the objection to embodied pedagogy (Gustafson, 1998). This phenomenon is even more pronounced in science education. Instructors may also reject approaches and opinions that challenge their early professional socialisation or their own social assumptions (Nguyen and Larson, 2015). More robust evidence is therefore needed to illustrate the importance of embodied learning to both teachers and learners. It is also necessary to identify a manageable framework for teaching and learning when employing embodied approach.

Thirdly, the challenges of embodiment theory itself may also influence its application in science education. It remains questionable if it explains the abstract content properly (Wilson, 2008) or whether it has become the mainstream of cognitive science, as some scholars argued (Laakso et al., 2011). Nevertheless, the change in cognition caused by embodied cognition illustrates the requirement of embodied turn in education research (Ionescu and Vasc, 2014). Although embodied cognition is still in its infancy, it could be valuable for educational practitioners, researchers, and/or policymakers and offer thought-provoking recommendations to promote and maximize the effectiveness of education practice (Shapiro and Stolz, 2019). This requires a clear understanding of embodiment when conducting embodied science education research.

2.1.4 Sociocultural Context and Science Education

As we discussed above, the ideas of cognition are embodied, which indicates that they emerge from physical interactions with the world. According to the radical version of embodiment discussed in Section 2.1.1, the study of cognition requires both ideas from a social and cultural perspective. This section will scrutinise the influence of sociocultural context on science learning and shed light on the complex interplay between learners' sociocultural environments and their cognitive development in scientific education.

Within the realm of science education, the exploration of sociocultural issues has been advancing since the 1980s. Various methodologies have been employed to examine the nexus between education and sociocultural factors, incorporating students' home languages, culturally relevant examples, and familiar resources into the teaching and learning process (Gay, 2002). For instance, investigations have delved into the adoption of social constructivist theory in science education at primary level within communities related to Confucian cultures, such as Vietnam, revealing the profound impact of cultural values and beliefs on teaching methodologies (Hằng et al., 2015). Moreover, research underscores the capacity of cultural considerations to redress disparities and injustices within science education, advocating for a more culturally inclusive framework to enrich science education (Parsons and Carlone, 2013). Presently, the cultural impact on science education has become a focal point of comprehensive research, illuminating the multifaceted ways in which cultural factors shape the pedagogy and learning of scientific content.

On the one hand, the integration of sociocultural factors has been shown as an effective way to promote students’ learning. It treats science classrooms as cultural spaces and recognises students’ cultural ways of being effective resources for science learning. For instance, Rahmawati et al. (2020) introduced an ethnopedology approach in science education, merging cultural learning with scientific instruction to examine its influence on student engagement and cultural identity. This method has been shown to create a significant and engaging learning experience for students. Li et al. (2021) conducted an intervention study in which they designed a science teaching approach which including introducing physics concepts to 24 children at kindergarten level via the storytelling method. The storytelling approach could transfer human characteristics to cosmic bodies through metaphors and relate it to participants everyday life. All scientific concepts in this study were explained in this way. The design also has follow-up hands-on activities and free drawing. After the programme, the children showed notable achievement in their understanding of the scientific concepts in this study. In chemistry education, context-based approach has been employed to engage student in chemistry by relate traditional chemistry concepts with everyday contexts (King and Ritchie, 2012). These studies have evidenced that it is effective to incorporate appropriate sociocultural factors for enhancing the conceptualisation of scientific concepts.

On the other hand, there is a need to ask questions about worldviews and the compatibility of various non-Western worldviews with modern science. Thinking through the assertions of Ogunniyi (1988) on modern science as a product of Western culture, this may not be readily amenable to the local worldview. Learners come into the science classroom with their own prior knowledge and experiences. For these learners to revisit their current thinking, they need to link up new information and create inferences and relationships between old insights and new ideas. Drawing on Simayi and Webb (2019) and their notion of knowledge restrictions when teaching some topics in sciences, Shumba, (1995) elucidates the conflicts that arise in the science classroom because some science topics might be taboo to specific cultures. For instance, in some Xhosa communities in the Eastern Cape Province of South Africa, it is deemed taboo to use standard human reproductive terms to teach human reproduction in Biology. Indeed, this position exists in many African societies. Okeke (2019) argues that it has been difficult for Western scholars to clarify several natural occurrences and issues in African life using scientific knowledge. This has resulted in a divergence between learners’ daily adventures in the home and the science classroom with most of the learners having significant difficulties in describing, understanding and predicting natural phenomena using Western scientific ideologies (Engelhardt et al., 2003).

Following these arguments, it can be seen that the specific sociocultural background could employ both positive and negative impacts on students’ learning. There are demands for culturally sensitive curricula and approaches to minimize this kind of foreignness (Aikenhead and Jegede, 1999). The construction of student’s prior knowledge carried to the science classroom cannot be separated from their religious beliefs and societal customs. Especially for students in developing countries, school science is perceived as a foreign culture since their cognition emerging from indigenous cultures has fundamental differences from the culture of Western science (Maddock et al., 1981).

The concept of indigenous science is important within this domain. Based on the definition of Aikenhead and Ogawa, (2007), indigenous science is described as a culture-dependent collective rational perceiving of reality. Indigenous science consists of the knowledge and practices relating to science in indigenous cultures, which provides various contexts that can assist understanding of the connection between sociocultural background and environmental ethics in specific communities (Zinyeka et al., 2016). Science knowledge has the capacity to explain some issues that indigenous knowledge cannot explain, and the reverse would be true. It is the teachers’ and educators’ responsibility to help indigenous students cross cognitive and social borders for science learning (Sutherland and Swayze, 2012).

A growing body of research has confirmed the non-negligible place of science education across cultures of indigenous knowledge. In order to facilitate knowledge and skills acquisition, and clearly express the applicability of this knowledge in their everyday life, the focus is on integrating science and indigenous knowledge (Mavuru and Ramnarain, 2020b). Several approaches have been utilised for this integration into science education. Gruenewald (2003) brings forward a critical pedagogy of place theory, which stresses three educational traditions for context-based education development. He suggested taking these traditions together and deeply analysing them with the diverse meanings held by different places and appealing to educators to consider the connection of education and place-specific culture. It provides a valuable theoretical framework for investigating science education in an indigenous context. What is more, Macalalag et al. (2020) also suggest incorporating social scientific issues as contexts and entry points engaging learners’ complex experiences to promote various learning outcomes. Zidny et al. (2021) presented that science education can be contextualised by indigenous science in a way that enhances students’ perception of science learning as relevant. In addition, it can also promote sustainability education. Including indigenous knowledge in school science education has been considered an important way to maximize the sociocultural relevance of science education for enhanced learning outcomes. In summary, research in this trend commits to bridging the conceptions acquired by students in specific cultural communities with science education.

Amongst this trend of research, cross-cultural issues also have received considerable attention. Researchers commonly compare the characters of students' conceptual understanding within two different cultural contexts. For example, Lahlou (2016) examined how the concepts of weight and mass are understood in Arabic and French, representing a non-Western and a Western language, respectively. The analysis of data from these two culturally distinct corpora revealed both similarities and differences in the meanings, prototypes, and metaphorical as well as metonymic extensions of these concepts, with a particular focus on family knowledge. Additionally, a multiple-case study was conducted with six middle school students from bicultural backgrounds to explore their experiences with culturally relevant activities (Kim, Kim, and Barnett, 2021). The findings demonstrated a bidirectional knowledge transfer between home and classroom, which engaged students, validated their home cultures, and supported their understanding of heat transfer concepts.

Except for this culture related information, within the scope of research investigating the diverse conceptual frameworks across various cultures, the role of language has been also identified as a significantly influential factor. Studies in sociolinguistics indicate potential linguistic challenges for ethnic minority groups, which can be attributed to the political implications inherent in language. This highlights the influence of language on cultural identity, particularly in the context of scientific education (Brown et al., 2005). Additionally, Salleh (2006) contends that language and culture are indispensable for efficacious science learning, emphasising their critical role in facilitating the understanding and communication of scientific concepts within educational contexts. This underscores the synergy between linguistic abilities and cultural capital in moulding educational experiences, thereby accentuating the importance of language in the cultural investigation of science education research.

However, even with this large amount of relevant research exploring the sociocultural influences on science education and various affirmative outcomes, there still exists a lack of consensus regarding optimal pedagogical strategies for integrating sociocultural contexts within science instruction (Mavuru and Ramnarain, 2020a). Science educators face difficulties in addressing students' sociocultural backgrounds due to the absence of clear, direct guidelines (Òtúlàjà et al., 2011). The reasons behind these difficulties could be linked to factors such as the students' level of education (Lubben et al., 1999) or the complexity of the specific scientific concepts being studied. Furthermore, the degree to which sociocultural elements affect students' scientific comprehension remains a matter of debate. Vosniadou and Brewer (1992) discuss how students from Greece and America exhibit parallels in their conceptualisation of the Earth, indicating a pervasive scientific understanding that transcends cultural distinctions (Tao et al., 2013). Consequently, a greater body of empirical research is imperative to thoroughly examine the interplay between sociocultural factors and student scientific reasoning and to ascertain effective methods for their incorporation into science education.

As expounded in the last section, the embodied approach has been reported to significantly contribute to science education by integrating various educational technologies. However, much of the research on embodiment has concentrated on individual cognition, particularly examining how students use their bodies to learn, either on their own or in small groups (Lindgren and Johnson-Glenberg, 2013). While these results may provide meaning perspectives into the role of the body in individual learning processes, they often do not fully acknowledge the extent to which individual cognition is embedded within a broader sociocultural milieu or consider the shared embodied experiences arising from this context. Without integrating the sociocultural dimensions of learning, embodied methodologies risk being marginalised in the design of formal educational settings and within the purview of research in Computer-Supported Collaborative Learning (CSCL) (Danish et al., 2020). Incorporating the situated sociocultural context into embodied science education may also enhance its acceptability among educators and students, thereby addressing the second challenge of embodied science education outlined in the previous section.

In conclusion, integration of embodied learning with a sociocultural lens could offer innovative insights into learning environment design within the scientific domain, whilst concurrently addressing extant challenges in the field. The combination of embodied practices and cultural context holds the potential to mutually enhance each other, effectively overcoming the distinct challenges each faces in science education. This symbiosis could lead to a more holistic educational approach that not only acknowledges the physical involvement of learners but also situates this within the rich tapestry of their sociocultural experiences. Nevertheless, the literature reveals a gap due to the limited data on understanding educational practices in specific cultural settings, especially from holistic and embodied perspectives. This area necessitates further research.

2.2 Specific Characteristics of Chinese Science Education

As a contextual lens for viewing and knowing the world, the sociocultural context has influences on learners’ cognitive processes and understanding directly. For science education, it has been demonstrated that science learning is influenced by cultural background and language usage, and it is facilitated when integrated into a cultural milieu that is relevant and meaningful to the students (Farenga et al., 2003). Moreover, science is also shaped by cultural factors (McComas, 2004). Thus, making science learning culturally relevant is of great importance for students.

As we discussed in the previous section, there is still not a unified framework for the integration of sociocultural factors and science education. In order to inform a sociocultural-based approach to students' science learning, a number of works have been conducted in this area. However, many of these are conducted in English-speaking societies, and relatively little research has been done on other social contexts. By analysing the publication patterns of several leading science education journals, Chu et al. (2019) conclude that there are very few papers focusing on science teaching and learning issues in Asia or involving participants representing the Asian diaspora. It is important to stress in this case that students' understanding of science and science concepts is also culturally dependent and varies from culture to culture. For example, a study undertaken by Park et al. (2021) found that Koreans who have an East Asian Confucian cultural background understand science from the perspective of how knowledge is recognised by other scientists, while Canadian students with a Western culture understood science from the perspective of how scientific knowledge is formed. This difference had an influential effect on their performance in science learning. The different finger-counting patterns of Chinese and Canadian students also impact their symbolic number manipulation (Morrissey et al., 2016). Therefore, to add the validity of science learning in a particular sociocultural community, more in-depth research is needed to identify its characteristics.

Chinese students have attracted significant interest from international education researchers due to their consistently strong performance in large-scale global assessments, such as the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA). As a typical Asian country, the study of China could also provide some insights for groups with the same cultural background. The remaining part of this section will provide an analysis of the characteristics of Chinese science education. It will present an analysis of several outstanding characters of the Chinese sociocultural context as well as illustrate how it may influence science education in China. Meanwhile, it will also provide a brief dialectical evaluation of embodied learning from a sociocultural perspective in such a context. These will help to better understand the context of the research and the subsequent discussion.

This chapter investigates the relevant research in the Chinese educational setting, contrasting the distinct aspects of science education with those found in Western cultures. Section 2.2.1 outlines the characteristics unique to Chinese science education, highlighting the differences in educational philosophies and practices. Section 2.2.2 particularly focuses on the language used in Chinese science education and its effects on conveying educational content. The final part, Section 2.2.3, considers the present issues and future directions for science education in China, focusing on educational resources, policy development, and the potential for international cooperation.

2.2.1 Differences between Chinese and Western Science Education

Science and science education studies in China have their own distinct background that is different from the Western world. On the one hand, this difference is due to the origin of science. Later in the twentieth century, as the origin of modern science, science was conceptualised as a subculture of Western culture (Jegede, 1995). This conceptualisation might make students from other traditional cultures consider themselves outsiders and not perceive themselves as included in the compulsory subjects. Among the science education in China, the majority of modern scientific terminologies used in modern science have to be translated into Chinese. The differences caused by translations sometimes lead to misunderstandings and alternative concepts of scientific knowledge (Gao, 1998). In the field of mathematics education, Han and Ginsburg (2001) demonstrated that Chinglish (Chinese words translated into English) often conveys concepts more clearly than English. This is because the structure of compound words in Chinese tends to represent mathematical ideas with greater precision. Awareness of this transition enables us to make better use of potential teaching resources and avoid hidden teaching risks.

On the other hand, the traditional Chinese culture also makes students’ understanding associated with science different. Cross-cultural comparative studies examining specific features of Chinese students’ conception of the nature of science have revealed significant differences in Chinese and Western students’ understanding of the nature of science. There are some particular perspectives held by Chinese students that are difficult to incorporate into Western categorisation frameworks. For instance, traditional Chinese thinking is mainly dialectical, while Western scientific thinking is mainly formal and logical (Peng and Nisbett, 1999). In particular, the Chinese philosophy of “天人合一 (man is an integral part of nature)”, “dialectical thinking”, “self-abasement” and “golden mean” have been influential mechanisms in the science literacy of Chinese students. The Chinese students' perception of science nature reflects the unique way of thinking and worldview in Chinese culture. Moreover, certain aspects of students' home cultures, such as their communication styles and interaction norms, may not align well with contemporary Western scientific practices (Solano-Flores and Nelson-Barber, 2001).

These differences are reflected in the differences in the understanding of science between Chinese students and Western students, which have the potential to hinder their science learning or to serve as valuable resources. The philosophical discontinuity between Chinese culture and modern science makes it difficult for students to grasp the nature of science. However, some of the theories from traditional Chinese culture such as 天人合一(man is an integral part of nature) deny the dichotomy of object and mind in Cartesian. In this case, embodied education in this context might be more acceptable and lead to better results compared to conduct in other communities. At the same time, this may also provide students with a different perception of the bodily experience, which could be used as resources for embodied approaches design.

Chinese science education employs specific teaching approaches deeply rooted in traditional Chinese culture. In this context, the student-teacher relationship is a social connection where the teacher often assumes an authoritative role. Teachers are viewed as respected figures who impart knowledge in a top-down manner, expecting students to listen, memorize, and follow established procedures rather than actively constructing knowledge themselves (Ginsburg, 1994). This approach is reflected in various Chinese proverbs, such as cramming a duck (滿堂灌), which metaphorically describes a teacher who dominates the lesson, emphasizing the teacher's central role in the classroom.

In Chinese classrooms, strict discipline and adherence to proper behaviour are prioritised over individual expression, independence, creativity, and overall personal development. This emphasis on expository teaching methods results in students who often display near-unquestioning acceptance of the information provided by their educators and are characterised as passive, quiet, and rote learners (Lim, 2007). This teaching style can be seen as an extension of the Confucian value of filial piety, which underscores respect for authority and adherence to traditional roles.

Traditional teaching methods in China are often considered non-productive. In order to overcome the weaknesses of this pedagogy model, Chinese educational scholars, as well as policy decision-makers, have initiated a series of science education reforms

(Zhang and Wan, 2017). Embodied education theory may provide new opportunities for improving this traditional model of teaching and learning. First, the embodied theory emphasises the active engagement of the body within the classroom. It might encourage the students' learning motivation, as well as improve the predominantly didactic approach. However, this mode of teaching might also create difficulties in the implementation of embodied education. At the same time, when the content is integrated with the cultural context familiar to students, they also take more initiative in the classroom, which might also alleviate the absolute dominance of the teacher in the classroom and further the establishment of a student-centred classroom.

2.2.2 Characters of the Language in Chinese Science Education

Language also presents different opportunities and challenges for science education in China. Chinese itself is a very distinctive language. As reported by Wang and Lin (2005), the structure of language has a strong impact on how native speakers perceive the world. Chinese characters are considered pictorial or symbolic representations, unlike English, where pronunciation is closely linked to spelling. As a result, Chinese students often encounter challenges that are distinct from those faced by English-speaking students. The processing of Chinese characters is found to be neurologically related to human body movements, or at least the imagination of them (Huang, 2013).

Except for the challenges from Chinese itself, as we mentioned above, many science concepts in Chinese are translated from original English concepts. Terms such as “net force” could express their purpose in a precise and concise way in English however lose this feature when translated into Chinese (Chen et al., 2018). Since translated science terminologies usually hard to find connections with the language students use in their everyday life, effective learning of science demands educators to understand the internal logic of translation and relate it to students’ daily experiences. Moreover, the meaning of a term might be different in a scientific or non-scientific context (Gao, 1998). Students also need to do translations between their daily language and science concepts.

Based on the works conducted by Cheng (2011), Chinese students’ alternative conceptions of science terminologies demonstrated associated the form of the Chinese character due to their radicals, which can be understood by the concept of the prefix in English. Moreover, when single Chinese characters are combined to form a term, students' interpretations are influenced by the meanings of the individual characters that constitute the term. In their research, Cheng (2011) found that 38% of elementary students in Taiwan identified Mercury (水銀) as a liquid rather than a metal. This confusion arose because the term consists of two characters—水 meaning water and 銀 meaning silver. Conversely, 25% of students mistakenly thought diamond (鑽石), which contains the radical 金 meaning gold in its first character, was a metal. Chiu (2007) conducted a six-year study on Taiwanese students’ conceptions in chemistry and concluded that Chinese characters both aid and obstruct chemistry learning. For instance, the radical 金, meaning gold, helps students categorise metals, while the character 酸, meaning acid, in the term carbohydrate, negatively impacts students' understanding. These researchers proposed that the Chinese written representation of concepts may create an additional embodied understanding of scientific concepts, which have the potential to facilitate students' science learning or, in other cases, may cause new problems in science education. Educators and education researchers need to realise and deeply comprehend students' embodied experiences in a specific cultural context.

Students' embodied experiences associated with language use are also related to the metaphor proposed by cognitive linguistics, a theory arising in the early 1980s and focusing on the embodiment of language. From this perspective, language, the primary source of communication, cannot be investigated in isolation from human embodiment (Evans and Green, 2009) since we have gone through the experience of reality by our bodily perception before we are able to have their so-called "concepts". These experiences are filtered by perception (Janda, 2015), which means our perceptions of one event or situation could be different. Therefore, language, in this case, is the reflection of our perception and understanding of reality. In order to explore the influence of the Chinese language on science learning, it is necessary to include the embodiment.

2.3 Learning of Scientific Concepts

Scientific concepts and principles serve as the foundational elements of scientific knowledge, with concept comprehension being a critical precondition for engaging in advanced scientific inference and practical work within the field (Reif, 1995). For science education, it is imperative that students achieve a deep understanding of these concepts. Proficiency in curricular concepts has been a crucial aspect of science and mathematics education worldwide for many years. According to the National Science Education Standards established by the National Research Council (NRC) in the United States, science education should focus on fundamental facts, concepts, principles, theories, and models that are essential for all students to understand and apply. This foundational document references the term concept(s) 97 times, including a comprehensive list of basic concepts as content standards for K-12 students, such as force, energy, and chemical reactions (Tang, 2011). Hence, it is evident that the learning of scientific concepts occupies a central position in science education.

The pedagogy of concept learning and the concepts it encompasses are perceived through various scholarly lenses, with multiple research trends exploring the learning of scientific concepts. One notable trend focuses on the application of diverse educational models like Problem-Project Based Learning and the scientific method, aimed at enhancing students' attitudes towards and command of scientific concepts (Dewa and Purwandari, 2021; Prasetyo et al., 2021). Another trend delves into examining students' initial conceptions and misconceptions of scientific concepts and crafting learning sequences to reformulate students' conceptual understanding (Nursa'adah et al., 2018). Additionally, significant emphasis is placed on the importance of grasping different representations of science concepts and processes, as well as employing multiple representations to facilitate the learning of scientific phenomena (Prain et al., 2009). Moreover, research is being conducted into the challenges and incorrect representations of scientific concepts, specifically focusing on learners' representations and their influence on the learning process (Jad et al., 2021; Neresini et al., 2009). Given the breadth of perspectives on the learning of scientific concepts, it is necessary to define the precise understanding of concepts and identify the specific aspects to be investigated in the current study.

This section is dedicated to unravelling the nature of concepts and the learning of scientific concepts, reflecting on the methodologies employed in this research to investigate the understanding of scientific concepts. Section 2.3.1 initiates a critical examination of the transition from the classical to the prototype view of concepts, shedding light on its repercussions for the epistemology of science education. it also probes the grade structure of concepts, with the aim of assessing its impact on the stepwise acquisition of complex scientific knowledge. Section 2.3.2 investigates the inherent attributes of scientific concepts, analysing their significance in underpinning conceptual comprehension and scientific deductive processes. Finalising this scrutiny, Section 2.3.3 focuses on students' misconceptions and links them with the embodied cognition theory mentioned in the last section.

2.3.1 From Classic View to Prototype View of Concepts

The classical theory of concepts posits that concepts are defined by a set of necessary and sufficient conditions that determine which objects fall under a given concept. This model does not stipulate specific criteria for these conditions. In the most simplistic instances, the conditions could denote a singular characteristic common to all objects under the concept but absent in those outside it. In more typical scenarios, this list, irrespective of its length, is considered to define a single complex predicate or property shared by all objects within the concept’s scope (McCain and Kampourakis, 2019). Nevertheless, this viewpoint has faced criticism for not consistently corresponding with empirical findings, with scholars arguing that real-world concepts do not always conform to strict conditions. This has led to assertions that the conceptual analysis based on necessary and sufficient conditions is fundamentally flawed, as it does not accommodate the often nuanced and complex nature of concept formation (Magnani and Nersessian, 2002).

Instead of necessary and sufficient conditions, alternative perspectives including prototype and exemplar views have gained prominence (Vosniadou et al., 2005). These alternative views propose that concepts are often represented by prototypes or specific exemplars embodying the most characteristic features of a concept. It implies that within a category, different members may share similarities with the prototype, even if they do not all possess the exact same defining features. This resonates with Wittgenstein’s notion of family resemblance, where members of a category exhibit overlapping similarities without conforming to a strict set of defining criteria (Nyström, 2005).

The importance of this perspective is especially significant in the context of science education since it primarily relies on carefully prepared teaching materials, which are designed to equip students with the skill to identify similarities between new problems and those previously solved (Kintē and Arabatzis, 2012). This skill appears to depend predominantly on the use of exemplary problems and concrete solutions, rather than on abstract descriptions and definitions. Based on the family resemblance, Kuhn developed a theory for scientific concepts wherein individuals acquire basic categories by learning to discriminate between similar and dissimilar features of category members (Andersen et al., 1996). This conceptualisation also led him to an account of categories and concepts akin to that of prototype and exemplar views, rather than adhering to the classical view. Therefore, according to Kuhn, the fundamental conceptual framework of science is a classification system that organises objects into groups based on their similarities. This grouping is not based on identifying necessary and sufficient conditions but rather on recognising and learning about the similarities and differences among objects. This perspective was further elaborated by Hoyningen-Huene in 1993, who used principles from classical mechanics, indicating that the most important instances of scientific concepts might be better understood as family resemblance concepts (Hoyningen-Huene, 1993).

The alternative view also challenges the traditional view of concept as having clear-cut boundaries and instead proposes that categories have graded structures, where items can belong to a category to varying degrees based on their resemblance to typical members of that category (Nosofsky, 1988). On the family resemblance view, category membership is determined from the degree of similarity and difference based not on a fixed set of features, but on a set of features that may vary. Hence, instances of a concept that are similar with regard to many features may be considered better examples of the concept than instances that share only a few of these features. Similarly, instances of a concept that differ from instances of contrasting concepts with respect to many features may likewise be considered better examples of the concept than instances that differ by only a few features. Thus, it is a direct consequence of the family resemblance view that concepts have graded structures.

Empirical studies indicate that people tend to evaluate all instances as better or worse examples of a given concept. Rosch and Mervis (1975) support this view by demonstrating that categories exhibit internal structures based on family resemblances rather than strict criteria. Furthermore, the study by Horowitz and Bedford (2017) highlights that categorisation involves graded structures, indicating that items can be categorised to varying degrees based on their resemblance to the typical category members. It shows that, rather than being equivalent, members of a category differ in how well they exemplify the category or how typical they are of it (Rips et al., 1973).

The presence of graded structure across various categories has been well-documented, suggesting that it is a universal characteristic of concepts. Seminal research by Rosch, Smith, and their colleagues demonstrated that common taxonomic categories, such as fruit and furniture, exhibit graded structures (Rips et al., 1973; Rosch and Mervis, 1975). Armstrong et al. (1983) observed graded structure in formal categories like odd numbers and squares. Lakoff (1986) reviewed evidence showing graded structure in linguistic categories, including phones, phonemes, and syntactic categories. Additionally, graded structure has been identified in categories such as human facial expressions (Ekman et al., 2013). At a more abstract level, significant studies have established graded structures for categories like spatial location phrases (Erreich and Valian, 1979) and psychiatric conditions (Cantor et al., 1980). Rosch's results were replicated widely across cultures and within cultures, using natural categories and artificial categories.

Affirming the universality of graded structures in conceptual understanding, their influence is instrumental in cognitive processes. Studies have consistently shown that individuals identify typical exemplars of a category more rapidly than atypical ones, pointing to the graded structure's central role in classification tasks (McCloskey and Glucksberg, 1979). Additionally, this structure predicts the number of exemplar generation within categories, with people tending to produce typical members more often than atypical ones (Barsalou, 1983; Mervis et al., 1976). The learning of categories is also influenced by this graded structure, as typical exemplars are assimilated with greater ease compared to atypical ones (Mervis and Pani, 1980; Rosch et al., 1976). Furthermore, the typicality of exemplars influences the decision-making process, significantly affecting outcomes (Cherniak, 1984). Comprehensive reviews by Mervis and Rosch (1981) and Smith and Medin (1981) explore the various roles of graded structure in categorisation tasks, underscoring its importance in cognitive functioning.

With the established impact of graded structures on categorisation and cognitive processes, it is pertinent to explore the factors that influence the formation and functioning of these graded structures themselves. Based on various categories examined by Barsalou (1985), factors such as central tendency, ideal exemplars, and the frequency of instantiations contribute to the unique variance in typicality across different categories. Lakoff (1986) identifies several additional factors that influence graded structure. It is clear that multiple reasons contribute to why certain exemplars are considered typical, and no single factor or fixed set of factors can account for this phenomenon entirely.

Among these factors, central tendency is one of the most significant in determining typicality. Central tendency refers to information that is prototypical or representative of a category’s members. This can be understood as modal or average properties abstracted from examples, a particularly representative exemplar, multiple representative exemplars, modal correlations of properties, or various other forms (Smith and Medin, 1981). In line with this view, understanding a concept involves recognising the typical or diagnostic properties of its referent (Machery et al., 2023).

2.3.2 Intrinsic Property and Scientific Concepts

The central tendency perspective, as proposed by the prototype theory, is connected to the concept of intrinsicness, a systematic philosophical idea rooted in ethical discourse and metaphysics (Allen, 2020).

To this day, the distinction between intrinsic and extrinsic properties continues to receive significant attention in the literature on ethical judgments and metaphysics. It argues that we intuitively distinguish ‘intrinsic’ from ‘extrinsic’ properties. There are various perspectives about how to identify and define intrinsic property. One perspective, tracing back to Moore (1993), holds that a property is considered intrinsic if it does not depend on any external relations. In other words, an intrinsic property is exemplified self-sufficiently, regardless of whether the object is observed alone or with others. As Langton and Lewis (1998) suggest, it remains constant regardless of the object's context. In brief, as Weatherson (2001) puts it, an intrinsic property does not depend on the ways of the external world. The consensus among these definitions highlights that a property is intrinsic if its manifestation in an entity is solely determined by the entity’s own nature, independent of any other entity’s nature or existence; all other properties are considered extrinsic (Littlemore and Taylor, 2014). Moreover, the concept of intrinsic property as the core property of concepts has been the subject of extensive investigation across various disciplines. In the realm of mathematics, the study of monoids has highlighted the need for a systematic examination of structures to better comprehend the intrinsic properties of mathematical concepts, indicating the significance of intrinsic properties in defining the core of mathematical concepts (Young-Loveridge, 1987, p. 198). Additionally, in metaphysics, the analysis of intrinsic properties has been essential in understanding the nature of categoricity and metaphysical theories, further supporting the notion that intrinsic properties may indeed form the core of concepts (Queiroz et al., 2021). This further supports the idea that intrinsic properties are fundamental in shaping the core of concepts.

In essence, an individual who understands a scientific concept is typically able to identify its key properties. Mastery of these central properties is crucial for effectively learning and distinguishing between scientific concepts. The central property, according to the argument of intrinsicses, is connected with the intrinsic property, since intrinsic properties are closely linked to the fundamental understanding and categorisation of concepts, indicating that intrinsic properties may indeed be considered the core properties of concepts.

2.3.3 Misconceptions of Scientific Concepts

The preceding discussion has introduced prototype perspectives of scientific concepts. Understanding these scientific concepts is consistently an important topic in science education. Anderson (2007) noted that the exploration of student conceptions across a wide array of scientific phenomena has become one of the most prolific research programs within the field. Within these conceptions, science misconceptions are defined as the knowledge individuals acquire through educational experiences or informal events, which are either irrelevant or incorrect when aligned with established scientific concepts (Gerardi et al., 2014). These errors have been referred to by various terms, including common sense beliefs (Halloun and Hestenes, 1985), preconceptions (Clement, 1982), or an intuitive sense of mechanism (diSessa, 1993).

Decades of research into conceptual development in science have thoroughly investigated the reasons for students' persistent and significant errors in common science problems. According to constructivism, which underscores the significance of learners' pre-existing knowledge and experiences during the educational process, students actively create their understanding of the world through interaction with their environment and by integrating new information into their pre-existing cognitive frameworks (Özdemir and Clark, 2007). The rise of misconceptions among students may be ascribed to this constructivist view, recognising that misconceptions can develop through the learning process and environmental engagement (Azizah et al., 2022). This notion aligns with the radical form of embodiment previously mentioned, which further emphasises the interplay among cognition, physical embodiment, and environmental interaction.

The impact of embodiment on students' misconceptions has been explored. Some misconceptions are thought to arise from everyday experiences with the physical world, where personal bodily sensations and experiences contribute to inaccurate beliefs about physical phenomena. They manifest as qualitative intuitions or preconceived notions that are stubbornly persistent, resisting modification even when faced with conventional teaching methods. A case in point is the belief held by students that "motion implies force", which originates from the everyday observation that objects do not continue moving unless acted upon by a force. The lack of a visible force, such as friction, which acts as a counterforce, is believed to be a significant factor in students' struggles to grasp Newton's First Law. These flawed intuitions typically stem from casual, isolated observations of daily occurrences, like seeing a ball roll to a halt on the floor. For example, when individuals are in a sharply turning vehicle, they may feel pushed against the door, which can lead to the incorrect belief that centripetal force acts outward from the centre of curvature. This illustrates how concepts of force may not only originate from physical experiences but are often shaped through embodied interactions (Lindgren and Tscholl, 2014). If cognition is indeed linked with bodily actions and sensations, it is reasonable to use bodily behaviour as a means to explore individuals' understanding—or misunderstanding—of scientific concepts, such as principles of physics. Thus, developing diagnostic approaches that are based on one's own bodily experiences can be valuable (Gallagher, 2006). The progression of computer technology, particularly in augmented and mixed reality, has opened the door to these types of immersive diagnostic environments.

Regarding the impact of sociocultural context, specific local knowledge has been proven can cause many misconceptions about scientific concepts. Moreover, it is also essential to consider the impact of language, especially as more students are learning science through a second language in many school contexts (Salleh et al., 2007). In 2015, Brookes and Etkina (2015) investigated how students' verbal expressions relate to their problem-solving approaches in thermodynamics. They interviewed 10 students from various physics courses at a large northeastern university about the thermodynamic cycle involving an ideal gas in a piston and cylinder. The qualitative analysis of these interviews led to two key findings. First, the methods students used to address heat-related problems were linked to their specific definitions of the term "heat." Additionally, students' tendency to incorrectly treat heat as a state function in certain contexts seemed connected to an implicit model of heat shaped by their language. This suggests that not only language patterns but also culturally specific metaphors can influence the learning of scientific concepts. For instance, a qualitative case study has shown that difficulties in understanding earthquakes may arise from the metaphor "tectonic plate," which is reinforced by everyday experiences and meanings (Dolphin and Benoit, 2016).

Except for the language students use for science learning, the translation of scientific concepts into different languages can significantly impact the learning of these concepts. When scientific concepts are translated from one language to another, there is a risk of incorrect translation, potentially leading to a misunderstanding of the concept (Dahlberg et al., 2023). This challenge is intensified when local languages lack equivalent scientific and technical terms, making the translation of scientific concepts highly problematic (Mack et al., 2013). Additionally, using both first and second languages in multilingual classrooms can disrupt the continuity of science learning, underscoring the need to carefully examine how language use impacts science education (Karlsson et al., 2020). The polysemy of words used to represent scientific concepts, students' prior knowledge of scientific terminology, and the mismatches between native and Western languages can further complicate the translation and comprehension of scientific ideas (Lahlou, 2016).

The challenges of translating scientific concepts are not limited to linguistic aspects but also extend to cultural and social contexts. For instance, back-translations can provide insights into how scientific concepts are conceptualised within specific cultural contexts, thereby enhancing mutual understanding of technical concepts (Klotz et al., 2023). Furthermore, the failure of translation in the arena of science poses challenges to the objectivity of scientific discourse, emphasizing the complexity of translating scientific knowledge across languages (McKenzie et al., 2011). The impact of translating scientific concepts into different languages on the learning process has been extensively studied. Studies have shown that translating scientific terms from Western languages into other languages can be difficult due to varying conceptualisations of physical phenomena across different languages (Lahlou, 2016). This suggests that the translation of scientific concepts requires careful consideration of cultural and linguistic nuances to ensure accurate and meaningful representation in different languages.

Currently, one of the primary ways in which the socio-cultural context is expressed and through which knowledge related to socio-cultural issues is acquired is via daily media. The influence of daily media on the learning of scientific concepts is a multifaceted issue that encompasses various forms of media, including digital, social, and traditional platforms. Research has shown that the use of everyday scenarios and science comic books has been found to facilitate the process of understanding scientific concepts, suggesting that the framing of science in daily contexts can impact students' reasoning and comprehension (Golumbic et al., 2022). Moreover, the representation of scientific information in popular media has been shown to influence public science knowledge and interest in science careers, indicating the potential impact of media on shaping attitudes towards scientific concepts (Szu et al., 2017). However, it is crucial to assess both the quality and accuracy of information presented in media, as factual correctness and the cultural context of science in popular media can profoundly impact public understanding of scientific concepts. The selection of sources and the management of instructional media can also play a crucial role in shaping students’ perceptions and interests in learning scientific concepts (Rozi and Rijal, 2023). These empirical results collectively demonstrate the potential of various media forms to enhance students’ understanding and engagement with scientific concepts, thereby contributing to the broader discourse on the impact of media on scientific learning.

The literature offers various perspectives on the nature and origins of scientific misconceptions, including the effects of embodiment and sociocultural context. Traditionally, identifying student misconceptions and fundamental understandings of physical phenomena has relied on clinical interviews and the creation of paper-based inventories, which use schematic diagrams and multiple-choice questions. While these tools have provided valuable insights into students' misconceptions, they may fall short in detecting flawed conceptions and rudimentary ideas that are not revealed through conventional testing methods. Advances in embodied science education present new opportunities for both teaching and diagnosing misconceptions. Lindgren and Tscholl (2014) illustrate this by describing how a full-body immersive simulation used with middle school students reveals misconceptions about object movement in space. More approaches should be investigated about how it can be employed for misconception identification.

2.4 Conceptual Metaphor Theory and Science Education

Cognitive linguistics has emerged since the early 1980s, positing that our metaphorical representations of the world are informed by speakers' perspectives and perceptions. In this process, metaphors serve as mirrors to our perception and comprehension of reality (Lakoff, 2008). It has also been found deeply connected with embodied experiences and context when constructing advanced cognition, especially for understanding abstract concepts.

Metaphors are not a new concept in the field of science education. It have been identified as pivotal for fostering meaningful learning and conceptualisation, as they make complex information easily accessible by using commonly known concepts (Celik, 2016). The application of metaphors in scientific contexts is especially beneficial for deepening understanding and facilitating the communication of scientific ideas. They enable learners to concretize abstract notions, encourage analytical thinking, and assist in explicating scientific theories (Negrea-Busuioc et al., 2022). They play also a fundamental role in linking scientific concepts, simplifying the grasp of intricate scientific ideas, and bridging the divide between common knowledge and scientific tenets (Niebert et al., 2012)

This chapter will present a comprehensive discussion on one of the most significant theories of metaphor: the conceptual metaphor theory, with a particular focus on its application in science education. Section 2.4.1 will scrutinise the traditional conceptual metaphor theory, with an emphasis on its classical interpretation that metaphor is a cognitive phenomenon rather than only a linguistic one. Section 2.4.2 will explore the extended conceptual metaphor theory, which embraces a wider spectrum of sociocultural influences and offers a framework for analysing the contextual factors in metaphor generation. This approach underlines the inseparable nature of metaphor and culture, accentuating the ongoing discourse regarding the influence of context on metaphor creation and its association with embodiment. Section 2.4.3 will further delineate the interplay between embodiment and context within cognitive linguistics and the process of generating metaphors. Finally, Section 2.4.4 will investigate the employment of metaphor in science education, acknowledging its utility beyond mere linguistic expression, as an instrument for elucidating scientific concepts and enhancing science learning. This section will highlight the transition from a linguistic to a conceptual grasp of metaphor in educational settings, propelled by its capacity to improve our understanding and implementation of educational concepts and methods.

2.4.1 Traditional Conceptual Metaphor Theory

There are two distinct perspectives on interpreting metaphor. The classical view holds that metaphor functions by conveying a concept through one or more words that are used in a non-standard or figurative sense (Geeraerts, 2006). According to this view, metaphor is seen as a special or poetic form of expression, separate from everyday language and thought. Metaphorical expressions were traditionally thought to be distinct from ordinary language: everyday language was considered free of metaphor, and metaphor was believed to operate through mechanisms outside conventional language use. This perspective was so widely accepted for centuries that many people did not realise it was merely a theoretical framework that had long defined the concept of metaphor.

The classical view of metaphor was first challenged by Reddy (1979). In his essay *The Conduit Metaphor*, through rigorous linguistic analysis, Reddy argued that everyday English is predominantly metaphorical, thereby refuting the traditional notion that metaphor primarily serves a linguistic function. Reddy's work shed light on the idea that metaphor originates from thought rather than language itself. In contrast to the classical view, which regards metaphors primarily as a linguistic device, contemporary theory emphasises their conceptual nature. This perspective considers metaphors as fundamental to conceptual understanding, conventional in use, and integral to both ordinary thought and language.

Lakoff and Johnson (1980) expanded upon the contemporary metaphor perspectives and introduced conceptual metaphor theory CMT in their influential book *Metaphors We Live By*. They argued that metaphor goes beyond its linguistic expression and deeply influences our cognitive system, shaping our understanding of the world. This view suggests that the essence of metaphor lies not in language itself, but in the way we conceptualise one mental domain through another (Lakoff, 1993). This is because according to CMT, our understanding of complex concepts is metaphorical, and achieved through the mapping between two domains. One domain is the source domain, which is concrete, physical, easily understandable, and readily accessible. The other domain is the target domain, which is abstract, complex, lacks physical characteristics, and is less easily accessed. In essence, metaphor allows us to map the complexities of abstract concepts on our knowledge and experiences in the more concrete and tangible domain. This mapping process shows that our metaphorical language is not only a linguistics device, but rather a cognitive activity that reveals underlying conceptual associations.

Due to these empirical findings, the term metaphor has evolved in contemporary research to signify a cross-domain mapping in the conceptual system. In this context, metaphorical expression refers to a linguistic manifestation (such as a word, phrase, or sentence) that represents this conceptual mapping, which was previously what the term metaphor referred to in older theories. Consequently, everyday abstract concepts like time, states, change, causation, and purpose are also understood to be metaphorical.

Within CMT, a prominent example is the metaphor LOVE IS A JOURNEY. This metaphor entails the comprehension of the domain of love through the prism of journeys — a seemingly disparate domain. More precisely, the metaphor is interpreted as a mapping (in the mathematical sense) from a source domain (journeys) to a target domain (love). The metaphor is constituted by ontological correspondences that transpose the ontology of travel onto that of love. Not limited to any specific word or phrase, the essence of the metaphor is the ontological transference between conceptual domains, from journeys to love. The metaphor facilitates the understanding and conceptualisation of LOVE via the everyday embodied experiences associated with JOURNEYS through this mapping process. Through the experiences of a journey, which includes movement, exploration, and progression, love is perceived as an evolving process with distinct phases, such as the commencement of a relationship and its various progressions and regressions. Each mapping consists of a set of ontological correspondences between entities in the source domain and those in the target domain. When these correspondences are activated, they can project patterns of inference from the source domain onto the target domain.

Another fundamental proposition of CMT emphasises the role of embodied experiences in human conceptual understanding. It proposes that the metaphor construction process, in which complex and abstract concepts are understood by relating them to more concrete concepts, is based on human sensorimotor and bodily experiences (Lakoff and Johnson, 1980c). It is through the mapping from a source domain to a target domain that embodied experiences, serving as the foundation for constructing the source domain, become central to our advanced cognitive processes. This perspective has gained increasing empirical evidence from the field of Embodied

Cognition, which also highlights the importance of embodiment in language, reasoning, and conceptual understanding (Shapiro and Stolz, 2019).

Regarding how embodied experiences shape our advanced cognitive process, within both the realms of Conceptual Metaphor Theory and Embodied Cognition, the concept of ‘image schema’ emerges as a pivotal concept in this process. Initially introduced by Lakoff (2008) and Johnson (2013), image schemas are defined as recurring, dynamic patterns in our perceptual interactions and motor activities that provide coherence and structure to our experiences. According to this definition, image schema emerges from perceptual and embodied experiences and serves to organise our experiences and comprehension. When comprehending abstract concepts, image schema can function as a foundational source domain for metaphorical mappings. It is the recurrent patterns of embodied experiences that emerge into image schema, which then serves as the foundation for the source domain in the metaphor production process.

To sum up, the claim of conceptual metaphor theory has two crucial effects. Firstly, from this point of view, language is not just a collection of symbols to represent the objective world but can also reflect people’s inner minds. We could learn about people’s perceptions and their experiences by investigating the metaphors they use. Secondly, the development of the metaphors people use is strongly linked to their embodied experience, and bodily interaction with the external world, which also provides an effective way for embodiment exploration.

However, the employment of this theory has also been criticised by some scholars for leaving examples out of discourse context, especially when using de-context factors such as image schema (Kövecses, 2008). On the one hand, the absence of examination into the pragmatics of metaphor in discursive contexts reduces the chances of investigating non-conceptual explanations for why people speak and write metaphorically, such as sociocultural and ideological forces (Gibbs, 2009). On the other hand, according to the radical perspective of embodiment (discussed in Section 2.1.1) addition to physical configuration, embodiment should also rely on sociocultural factors. As expressed by Sinha and Jensen (2001) when defining embodiment in metaphors, some researchers have failed to recognise the role of culture and society in human cognition. The importance of embodiment in conceptual metaphor also requires attention to the context. Many researchers have therefore started to explore a more dynamic and extended version of CMT.

2.4.2 Extended Conceptual Metaphor Theory

The preceding section outlined two principal assertions of traditional CMT, detailing the construction of metaphors from embodied experiences, and advocating for revisions to its conventional form. A significant contemporary shift in metaphor research is the increased focus on the sociocultural context in generating conceptual metaphors, recognising that embodiment is not the exclusive foundation for all metaphors in language and thought. This section will discuss this in detail.

According to CMT, metaphors could be categorised into three layers based on their underlying ‘conceptual materials’. The first layer is known as primary metaphors (Lakoff et al., 1999). It exhibits a near-universal presence and is closely intertwined with the previously mentioned image schemas and embodied experiences, which serve as the principal factor in the formation of these metaphors. This is closely related to the relationship between metaphor and embodiment. The second layer comprises culture-specific metaphors, which predominantly arise from shared cultural values and the collective understanding within a community. The impact of culture on mental processes and individuals’ modes of thinking has been well-established in various research fields. If we accept the central premise of Conceptual Metaphor Theory, which posits that metaphors primarily shape our advanced mental processes, it follows that metaphors are inevitably influenced by cultural factors. Consequently, when analysing metaphors, it becomes imperative to account for the role of cultural influences. The third layer involves individual creativity and personal experiences. Metaphor construction exhibits a significant degree of personal inclination. Furthermore, the utilisation of metaphors in discourse displays substantial variability. This variability stems from the crucial role played by context in determining the selection of metaphors in a given situation. For instance, as proposed by Fang (2006), different students may generate distinct metaphors in varying contextual scenarios. It is evident that the factors influencing metaphor generation extend beyond embodied experiences and encompass numerous other elements. These two layers are closely related to how metaphor relates to context.

In cognitive linguistics, sociocultural factors are increasingly recognised as significant influences on the development of metaphors. For instance, within the framework of CMT, metaphors such as *he's wasting time*, *I have to budget my time*, and *this will save you time* emerged around the time of the Industrial Revolution. During this period, people began to be compensated based on the amount of time they worked. The factory system led to the institutional association of time with monetary value, forming the experiential basis for these metaphors. Since then, the concept of budgeting time has become widespread in American culture. There is also a conceptual metaphor where the eyes are limbs and vision is achieved when the object seen is touched (Kövecses, 2002).

The influence of sociocultural context on metaphors is also reflected in the varying use of metaphors across different cultures. For example, the conceptual metaphor of TIME manifests distinctly in different linguistic contexts: it is often depicted as vertical in English, contrasting with the frequent horizontal characterisations found in Mandarin (Boroditsky, 2001, 2007). A similar divergence is observable in expressions related to comprehension and knowledge. In Western discourse, the acts of seeing and blindness are metaphorically employed to signify understanding or the lack thereof. Conversely, research by Evans and Wilkins (2000) demonstrates that in certain Aboriginal Australian cultures and languages, comprehension is metaphorically aligned with *hearing* rather than *seeing*. Therefore, as posited by Johnson (1997), while the physical body's configuration is a critical component of embodiment, the influence of cultural context is equally indispensable.

For the important mental instrument, image schema, proposed by traditional CMT, Johnson elaborates that image schemas, which are instrumental in metaphor construction, stem from individual-specific experiences, necessitating an interpretation that includes the qualitative attributes of those experiences (Johnson, 2013). In concordance, Gibbs champions a more dynamic view of image schemas, reinforcing the notion that metaphors are a confluence of diverse and interactive factors (Gibbs, 2005). This research trajectory has prompted scholars to explore metaphorical language beyond traditional similitude or 'A is B' metaphors and beyond the scope of embodiment itself (Glucksberg et al., 2001). Such an approach is encapsulated by the term *Extended Conceptual Metaphor Theory*.

As cognitive linguistics increasingly explores the interaction between culture and conceptual metaphor, many researchers recognise the crucial role of culture in shaping these metaphors. These empirical findings highlight that the understanding of metaphors is deeply connected to both embodiment and context. This underscores that interpreting metaphorical language is not just a cognitive process detached from the physical and cultural environment. Instead, it is deeply interwoven with the sensorimotor experiences that define our embodiment and the sociocultural contexts that shape our conceptual frameworks. However, there is still an important debate that remains under-explored, which is the role of embodiment play in this process.

2.4.3 Embodiment, Context and Metaphor

From the foregoing analysis, it is recorded that both embodied experiences and sociocultural factors are fundamental to the interpretation of metaphors. It is worth mentioning here that these factors are not independent but rather mutually influential. However, it remains uncertain about the rationale behind the variation of metaphor, and the precise relationship between these two dimensions remains insufficiently demonstrated by research. The significance of situated context in the construction of metaphors has been a prominent discourse within the realm of CMT since the late 20th century. Although consensus within the field acknowledges that culture and metaphor are inextricably linked (Steen and Gibbs, 1999) and that no metaphor exists in a cultural vacuum, however, debates still persist regarding the extent to which context influences metaphor construction and its interplay with embodiment.

To explore how culture influences metaphor, some scholars have proposed the idea of cultural filtering. This concept suggests that while certain conceptualisations may capture universal human experiences, language-specific interpretations or elaborations often reflect experiences that are particularly significant within a given sociocultural context. Cultural filtering affects how universal embodied experiences are utilised and results in variations in metaphors across different cultures (Ansah, 2013; Zibin and Hamdan, 2019). According to this theory, some metaphors may be universally applicable, while others are specific to particular cultures (Kövecses, 2005).

The classification of metaphors is associated with the distinction between two types: primary metaphors and complex metaphors (Lakoff et al., 1999). Primary metaphors are fundamental, often universal, and arise from basic, shared human experiences. In contrast, complex metaphors, which combine primary metaphors with cultural beliefs and assumptions, tend to be culture-specific. About the universality of metaphor, which means metaphors containing universal models that can be applied to genetically unrelated languages and cultures (Türker, 2013), the most popular interpretation is this universality is formed through universal human embodied experience, which is also referred to as physiological embodiment, asserting that the universality of metaphor is because all human being share a basic image-schematic structure based on the similarity in the human body and function (Maalej, 2004). This approach is used by many scholars exploring concepts in the field of emotion (Zibin and Hamdan, 2019) and medicine (Gibbs, 2020; Yu, 2003).

It has been suggested that primary metaphors originate from experiential correlations or “conflations in everyday experience” that link subjective experiences and judgments with sensorimotor experiences. In these metaphors, sensorimotor experiences serve as the source domain, while subjective experiences or judgments constitute the target domain. Consequently, primary metaphors are considered to derive directly from our experiences—often from shared bodily experiences—and are thus more likely to be universal. Conversely, complex metaphors are said to be formed by conceptual blending (Lakoff and Johnson, 1980b), constructed from primary metaphors together with widely accepted cultural knowledge, models, folk theories, or beliefs. Grady (1999) explains that primary metaphors are anticipated to have the widest cross-linguistic distribution and are more likely to be universal. This contrasts with complex metaphors, which are culture-specific and consist of combinations of primary metaphors. The delineation between universal and culture-specific metaphors illustrates how both embodied experiences and the context of situated culture collaboratively give shape to the emergence of concepts.

This perspective prefers to take culture as a filter of the universal source domain, which selects and combines the metaphorical maps from the many possibilities, elaborates and then conventionalizes them in a linguistically effective manner (Yu, 2009). This argument is considered an extension of embodied cognition theory and is labelled as cultural embodied cognition, which integrates culture with embodiment and metaphor to a certain extent but keeps embodiment as the basis for metaphor and human cognition. Proponents of this trend have given empirical evidence to support their arguments, maintaining embodiment as the core point, positing that the role of context is to shape embodiment. For example, the face could be constructed as a universal source domain for understanding dignity and prestige metaphorically. Yet Chinese- and English-speaking cultures have different extents of expression regarding saving one’s own and other people’s faces since Chinese culture puts great emphasis on a person’s social face. From this perspective, culture acts as a mediating mechanism that transforms universal, physical, and sensorimotor experiences through the lens of complex, socially acquired beliefs, knowledge, and worldviews specific to one or more cultures (Caballero and Ibarretxe-Antuñano, 2009).

Contrary to this opinion, the growing body of work in cross-linguistic CMT has revealed that culture should be viewed not as a fixed set of knowledge and values, but rather as a rich resource that individuals can use to generate meaningful stories and experiences (Pritzker, 2011). In the development of culturally embodied cognition, Kövecses (2008) proposed body-based social constructionism, which indicates that conceptual metaphor is based on not only the bodily experiences but also the context it is situated. Both the body and the context motivated the existence of metaphor. In most cases, these two factors interact but operate at different levels. Consequently, metaphors can be classified into three categories: those primarily motivated by bodily experiences, those influenced by both bodily experiences and cultural factors, and those predominantly driven by cultural factors (Kövecses, 2019). In his recent book

Extended Conceptual Metaphor Theory (Kövecses, 2020), he proposed four types of contextual components that can impact the metaphor generation process. Within this explanation, context is no longer an appendage to interpreting the embodiment, but rather a separate element that has the same status as the embodiment when constructing metaphors.

This perspective is reinforced by Ibarretxe-Antuñano (2013), who suggests that culture not only filters the bodily-based information to enable only certain cultural elements to pass but also impregnates the mapping of a concept to the conceptualisations in a given culture. From this standpoint, in the metaphor-construction process, culture not only influences the selection of universal embodied experiences but can also constitute the source domain in its own right. Consequently, culture-specific metaphors encompass not only complex metaphors but also those for which the source domain is shaped exclusively by cultural determinants.

In conclusion, from the foregoing discussion on the roles of embodiment and sociocultural context in metaphor construction, metaphors can be divided into two broad categories. The first category comprises universal metaphors, which are founded upon embodied experiences that are widely shared and draw from these experiences as their source domain. The second category consists of culture-specific metaphors, which are derived from sociocultural factors, whether by influencing embodied experiences or by employing these sociocultural elements as the source domain itself.

2.4.4 Metaphors in Science Education

Metaphors play an important role in science communication by helping to explain complex concepts in a more understandable manner. It is also integral in driving scientific insight, experimental design, and the development of paradigms across diverse scientific disciplines (Aviram and Manella, 2020). Wilson and Gowdy (2015) discuss the pivotal role of metaphor in science, emphasizing how it aids in the explanation of abstract and intricate scientific ideas. This is particularly crucial in science education, where students often encounter challenging and abstract concepts.

Regarding the conceptualisation of scientific concepts, the role of metaphor can also not be ignored. A key function of metaphor in science is to clarify concepts and theories in specific fields. For instance, in physics, electricity is often conceptualised as a fluid, and electrons within an atom are likened to a solar system (Wan and Low, 2015). Building a bridge between unfamiliar scientific concepts and more familiar everyday experiences, it has been utilised to enhance scientific understanding and learning, including comprehension, retention, and also pedagogical process (Odabasi et al., 2019). Furthermore, metaphors have been studied in various subfields, including computer science education and human-computer interaction, where they have been found to have effects on programming problem-solving (Hidalgo-Céspedes et al., 2018).

Moreover, metaphor usage in science education is crucial for broadening teachers' insights into their students' conceptions and can either support or impede learning, contingent on the interplay between scientific and spontaneous concepts within educational discourse (Daane et al., 2018; Hardman and Set, 2021). It needs to be stressed that the source domain of a metaphor significantly impacts its use in science learning. In the context of science learning, the selected instrument for metaphor use should be familiar to children, find its meaning in everyday life, and have its link clearly established (Memişoğlu and Erçelik, 2022). The use and abuse of metaphors when teaching and learning science can sometimes confuse students (Jakobson and Wickman, 2007). Niebert et al. (2012) indicated that when understanding certain scientific issues or communicating science, educators should relate it to students' embodied metaphors, in other words, direct experience for more effective science learning, indicating that effective educational metaphors need to refer to the source domain that students understand directly.

Empirical research has demonstrated a significant connection between embodied cognition and metaphor in science education. The creative engagement with embodied metaphors has been recognised as a developmental process that helps learners transform their initial, often fragmented ideas into more coherent, scientifically accurate, and personally relevant concepts (Anderson, 2018). Studies have shown that interaction models grounded in embodied knowledge, facilitated through embodied metaphors, can effectively support children's understanding in abstract areas (Bakker et al., 2012). Furthermore, the embodied sources of metaphors are everyday experiences conceptualised in schemata such as containers, paths, balances, and up and down, highlighting the strong connection between embodied experiences and metaphorical understanding in science learning (Niebert et al., 2012).

Moreover, research on metaphors in science education has also highlighted the importance of teachers understanding conceptual metaphors and observing students' use of these metaphors. Such observations can serve as a valuable tool for formative assessment, helping educators gauge and support students' grasp of scientific concepts (Daane et al., 2018). Metaphors also have the potential to be used as a tool for understanding meaningful learning and conceptual formation in science teaching, particularly in subjects such as physics and biology (Celik, 2016). In physics education, diagnosing students' misconceptions typically relies on paper-based or web-based schematic tools, which often include descriptive or explanatory text. These tools present scenarios that require applying physics principles, such as identifying forces acting on an object thrown upwards. Students may be asked to describe these forces or choose from several drawings that illustrate the correct forces with arrows. Exploring metaphors could offer a novel approach for investigating and understanding scientific concepts, leveraging their exploratory nature to enhance comprehension.

2.5 Summary of Literature Review

This chapter commenced by positioning embodied cognition as a divergent viewpoint from the standard cognitive theory. It emphasised the importance of bodily interactions and physical experiences in the cognitive process. The research presented advocates for a pedagogical shift in science education towards utilising students' physical engagement as a means to enhance their learning outcomes.

Embodiment extends beyond mere physicality; the radical interpretation of embodied cognition also assigns a pivotal role to situational context in cognitive processes. Thus, embodied science education and related research should not overlook the significance of context. Unlike previous approaches that may have neglected the body's role, the sociocultural environment has consistently been recognised as a crucial element in science education. The unique sociocultural backgrounds of students, their linguistic practices, and the emergent information from these contexts can exert both beneficial and adverse effects on their learning in science.

Research also substantiates that incorporating sociocultural perspectives can mitigate some intrinsic constraints of embodied science education, such as its occasional disregard for the educational milieu and the challenges it faces in gaining acceptance among educators. Additionally, Section 2.3.3 reveals that many student misconceptions are rooted not only in intuitive embodied experiences but also within their sociocultural environments, thereby underscoring the imperative to examine both elements in depth within the realm of science education.

The trajectory of this research holds significant implications for science education in China. As delineated in Section 2.2, Chinese science education exhibits unique features that distinguish it from Western methodologies, including aspects of student comprehension, pedagogical approaches, and language utilisation. Furthermore, there is a notable scarcity of scholarly investigations that specifically address the application of embodied cognition theory within particular sociocultural contexts. Consequently, examining the Chinese educational setting could illuminate this area of research, offering new insights into the integration of embodied cognition theory within diverse cultural frameworks.

Section 2.3 elaborates on the comprehension of scientific concepts, aligning this discussion with the broader research into conceptual understanding in science education. It begins by charting the evolution of perspectives on scientific concepts from a classical view, which focuses on defining concept boundaries, to a prototype view that emphasises understanding through examples. This shift suggests that learning scientific concepts involves recognising their graded structures by grasping central tendencies. This notion relates to the definition of intrinsicses in metaphysics, which underscores a property’s inherent nature, independent of any other conditions and relationship. Such an understanding is crucial for the effective teaching and research of scientific concepts, pinpointing the core aspects we must emphasise.

The preceding content underscores the importance of examining both embodiment and the sociocultural context in the formation of scientific concepts, as well as the focal points for understanding concepts within this research. Building on these premises, Section 2.4 introduces CMT as a framework that interweaves embodiment, context, and cognition, offering a novel lens for research in this domain. CMT posits that metaphor transcends its function as a linguistic device and is deeply intertwined with human cognition, encapsulating our comprehension of the world. The construction of metaphors is rooted in our embodied experiences and the specific sociocultural contexts we inhabit. This theory suggests that metaphors are not only valuable for drawing out students' conceptual understandings but also for linking these concepts to embodied experiences and the surrounding environment. CMT aligns with both theoretical perspectives and practical research methodologies. The subsequent section will delve into some theoretical considerations for employing metaphors as investigative tools.

2.6 Theoretical Framework of this Research

The preceding chapter advanced the proposition that tighter integration of students' physical embodiment with their contextual surroundings is pivotal for deepening conceptual understanding. It also canvassed significant studies in the domain of science education. Facing these challenges, it is essential to clearly articulate this research's perspectives on embodiment.

The upcoming section will offer a review of the metaphor, embodiment theory and its interplay with context, thereby defining the theoretical stance of this study. Section 2.6.1 addresses the methodological concerns in investigating understanding through metaphors, which is the distinction between conceptual metaphors and linguistics metaphors. Section 2.6.2 engages with the debates around the contributions of embodiment and context to metaphor generation and delineates the research's stance on these interactions. Section 2.6.3 examines the diverse perspectives of embodiment and details the specific approach to embodiment that will be utilised in this study. Section 2.6.4 introduces Vygotsky's sociocultural theory and how it defines the investigation of culture in this research. Section 2.6.5 introduces an elaborated theoretical framework that captures the study's perspective on embodiment, context, and Conceptual Metaphor Theory. This framework is intended to synthesize various theoretical standpoints and lay a cohesive foundation for the research.

2.6.1 Investigating Students' Understanding through Metaphors

Previous discussions have highlighted that a primary focus of CMT is human reasoning, which is characterised by its imaginative nature. According to its claims, human reason is imaginative, which means thinking of the world in alternative ways to construct alternative construal. Metaphors, as one of the major imaginative devices to emerge such alternative construal, is generally defended that the knowledge structure of an abstract, non-physical domain (target domain) is conceptualised by the sensorimotor experience of a more concrete, physical domain (source domain) (Lakoff and Johnson, 1980c). It is the similarity between the two domains that is considered to be the main reason for developing conceptual metaphors (Kövecses, 2020). Moreover, CMT highlights that the creation of metaphors is influenced and limited by an individual's specific bodily and mental configurations, as articulated by the concept of embodiment. It is shown that cognitive linguistics is the theory combining both language and the concept of embodiment, and also provides an effective way for researching the interrelationship between psychological processes, body, and environment. It not only enriches embodiment ontologically but also provides a viable methodology and facilitates research methods for this inquiry. According to CMT, metaphor could be used as a practical investigation tool for conceptual understanding. However, an important theoretical issue needs to be addressed for the analysis process of metaphors, which is the distinction between *conceptual metaphor* and *linguistic metaphor*.

The mapping in conceptual systems we mentioned above was initially defined by Lakoff and Johnson as a conceptual metaphor (Lakoff and Johnson, 1980b), which involves understanding one domain of experience in terms of another. They also distinguish ‘one-shot’ or linguistic metaphors, which are not conventionally used in everyday reasoning and are less systematic in nature. These perspectives have led to a two-way view of metaphor in cognitive linguistics (Kuna et al., 2022). One approach analyses metaphor as moving from conceptual metaphor to linguistic metaphor, focusing on how individuals’ conceptual knowledge influences their linguistic behaviours. The alternative approach views metaphor as moving from linguistic metaphor to conceptual metaphor, explaining linguistic behaviour and inferring conceptual knowledge, including metaphorical mappings (Cornelissen, 2006).

In this study, we have adopted the latter approach, wherein linguistic metaphors serve as the foundation for investigating students’ comprehension of scientific concepts. Consequently, the establishment of a suitable process for constructing conceptual metaphors from linguistic metaphors assumes paramount importance. Within the scope of this particular research field, Steen (1999) introduced a five-step method for constructing conceptual metaphors from linguistic metaphors. This method has gained widespread recognition and has been extensively employed for constructing conceptual metaphors in various fields (Wan, 2015). However, despite its widespread use in numerous studies, unresolved issues remain regarding the effective construction of conceptual metaphors from linguistic metaphors.

The primary concern is the challenge of distinguishing between linguistic and conceptual metaphors. Although Lakoff and Johnson (1980a) put forth six criteria to differentiate ‘conceptual’ and ‘one-shot’ metaphors, the subjective nature of determining whether a linguistic metaphor belongs to one category or the other remains. Additionally, it is important to note that this question cannot be definitively resolved by relying solely on linguistic data (Deignan, 2016). Steen himself recognised this limitation and emphasised that:

> “If one insists on regarding as conceptual metaphors only those metaphors which are systematic (as opposed to one-shot metaphors), which I do not, then a sixth step will have to be added to the procedure, saying that the output of the first five steps is to be compared over large numbers of metaphors in order to establish more or less systematic groups of metaphorical concepts, labelling the largest systematic groups as conceptual metaphors.” (Steen, 1999, pp. 59)

Furthermore, there is an increasing recognition of the impact of various factors on the selection of conceptual metaphors for a given topic. These factors include the audience, the speaker’s personal experiences and cultural background, as well as their familiarity with the subject matter. Such recognition poses a challenge to the notion of a shared and unchanging collection of conceptual metaphors. To illustrate this, Deignan, Littlemore, and Semino (2013) conducted multiple studies examining metaphor use across various genres and contexts. Their research revealed that different groups of language users utilise different metaphorical resources when discussing the same subjects. As a result, the utilization of metaphorical language can vary significantly, potentially leading to misunderstandings. Consequently, this evidence undermines the notion of a universally fixed set of conceptual metaphors.

As mentioned earlier, this study indeed takes a departure from students’ linguistic metaphors to investigate their conceptual understanding. In line with these arguments, the two key issues in light of this approach need to be addressed.

Regarding the first issue concerning the distinction between linguistic and conceptual metaphors, an examination of various examples reveals that these two categories are not entirely separate, as linguistic expressions often incorporate the names of specific conceptual metaphors. For example, the metaphor GOOD IS UP can be both linguistic and conceptual metaphor. This observation aligns with Steen’s argument that even so-called one-shot metaphors possess conceptual characteristics (Steen, 1999). In other words, whether a metaphor is used sporadically by an individual speaker or established conventionally within a society, it can still reflect the underlying conceptual system of the speaker. This understanding implies that the boundary between linguistic and conceptual metaphors is not as rigid as initially perceived. Rather, it suggests that the distinction is better understood as a continuum, where linguistic metaphors can simultaneously exhibit conceptual properties. Moreover, it is important to emphasise that the focus of this study is not to generalise the specific metaphors generated by the participants but rather to gain a deeper understanding of students’ thoughts and conceptualisations through an analysis of their metaphor use. Every metaphor could provide valuable insights into their cognitive processes and how they make sense of complex scientific concepts.

Regarding the second issue concerning the subjective nature of conceptual metaphors which lead to variation in metaphor use across different situations, this particular aspect serves as a central focus of investigation within this study. The research aims to delve into how the unique Chinese cultural background shapes students' comprehension of scientific concepts and their utilisation of metaphors. It is essential to note that metaphors, in addition to their conceptual nature, also carry affective implications that can convey a wide array of effects and emotional nuances (Cameron, 2010). Taking a de-contextualised approach that solely examines the shift from linguistic metaphor to conceptual metaphor would overlook valuable information that is intertwined with culture, individual speakers, and the necessity for further nuanced analysis. Recognising the profound influence of cultural factors, alongside individual and contextual elements, is imperative in comprehending the intricate interplay between metaphors and the specific sociocultural context in which they are employed. By acknowledging these multifaceted dimensions, a more comprehensive understanding of students' metaphorical usage and its broader implications can be achieved.

In conclusion, the discussion surrounding the distinction between linguistic and conceptual metaphors, as well as the recognition of varying metaphor use in different situations, has led to a more inclusive and comprehensive approach to metaphor analysis in this research. The arguments presented in this section emphasise the necessity of moving beyond rigid categorisations of metaphors and, instead, focusing on their analysis as reflections of students' thinking processes. Consequently, in this study, the identified metaphors will not be strictly differentiated as 'conceptual' or 'one-shot', but rather all examined as valuable insights into students' cognitive frameworks and their conceptual understanding of scientific concepts. This inclusive approach enables a deeper exploration of the rich and multifaceted nature of metaphors and their significant role in shaping students' comprehension.

2.6.2 Perspective of Embodiment in This Research

Section 2.1 provides an exposition of various trends within embodied cognition. As mentioned before, presently the notion of embodiment is far from uniform in the commitments it entails (Zwaan, 2021). In science education, researchers frequently use the concepts of embodiment and embodied cognition interchangeably or fail to address the complexities inherent in these concepts altogether (Kersting et al., 2021). Therefore, it is important to make it clear about what embodiment means in this research here for constructing common sense for the following discussion. This section aims to synthesize the embodied theories discussed above and to propose the perspective of the embodiment that will be employed in this research.

The main debate about embodiment is regarding how the body functions in advanced cognitive processes, which is situated in the differences between moderate and radical versions of embodiment. The moderate version of embodiment is aligned with the neurocentral assumption and computational account, which consider an individual's mind and brain as synonymous. This contrasts with the claims of radical embodiment that an individual's nonneural body is a constitutive part of her mind. Some scholars argued that the bodily formatted representations suggested by moderate embodiment are nothing other than brain processes (Bruin and Gallagher, 2012), making this standpoint no more fundamental difference compared to the standard cognitive science. It is also crucial to recognise that cognitive processes unfold over time, with the elements of a cognitive system constantly evolving. Therefore, a cognitive model that can account for these ongoing changes is essential. The coupling relationship between the brain, body, and world proposed by dynamical system theory in radical embodied cognition ensures the brain's activities are not understood in isolation and emphasises that these activities take place in the body and world. It has significant relevance for education research. In the broad sense, learning is not supervenient for the brain, but the entire mind-brain-body-world nexus. Therefore, a radicle version of embodiment might be more consistent in the education context and able to contribute to how education could make use of both embodiment and context aspects.

Drawing from Merleau-Ponty's (1979) work, Thorburn and Stolz (2020) reconceptualised the nature of embodied learning experiences and their implications for education. Merleau-Ponty contends that the totality of the whole "body-subject" provides a devising idea relating to the body and the environment. Embodied learning experiences are deeply rooted in cultural contexts, where unconscious societal values influence preferences and group loyalties. For the individual learner, this form of learning involves gaining a deeper understanding of oneself and one’s surroundings—not merely as abstract entities or tools but as a lived body that actively senses and engages with the world in a meaningful way (Stolz, 2015). According to these arguments, learning should be approached as embodied and also embedded in culture.

However, much of Gibson’s work concentrates on the naturally occurring features of the environment rather than on environments shaped by human activity. It is important to recognise that affordances in human-designed environments may differ significantly from those in more general, non-human contexts (Gibson, 2014). Gibson recognised that humans are shaped by their environments, yet his approach to understanding people often mirrored his approach to objects (Pedersen and Bang, 2016). While ecological perspectives emphasise the interaction between humans and their environments, they often overlook the critical sociocultural dimensions of human experience. The sociocultural embodiment, in this case, could be seen as one aspect of the environment exploration in the dynamical system theory. If we recognise embodiment as a theory that takes the body as an intersubjective ground of experience, studies under the embodiment banner are not about the body per se. Instead, they are also associated with sociocultural factors and experiences insofar.

As Rohrer (2007) argued, the scope of embodied cognitive science extends beyond just physiological and neurophysiological factors and includes not only interactions between the body and the physical environment but also the social and cultural experiences of the body. In other words, it is essential to consider the sociocultural context in which an individual body is situated. Hence, the exploration of the embodiment will also need to focus on how the sociocultural environment around us impacts our embodied experiences and how this process will affect or could be used to promote the cognitive process.

Integration with a sociocultural perspective can also overcome the shortcomings of embodied learning itself mentioned in Section 2.1.3. Nguyen and Larson (2015) observed that both teachers and students often exhibit resistance to embodied learning. This resistance arises because embodied learning challenges the traditional teaching methods with which they are familiar. In education, students often expect learning that affirms their knowledge and sense of self-identity (Kumashiro, 2002). What’s more, embodied pedagogy may also face the challenges of physical as well. Factors such as gender, culture, power, and size can interfere with embodied education (Gremillion, 2005). For example, Lugo-Lugo (2012) reported experiencing resistance in the classroom related to her ethnicity and gender as a Latina faculty member. Both teachers and students were found to be somewhat resistant to embodied learning, due to issues such as identity and a lack of alignment with their expectations. Integration with a sociocultural perspective ensures that the content of embodied learning is relevant to their everyday experiences and facilitates the acceptance of the embodied approach in science education.

This study is concerned with how context impacts the learning process through bodily experiences. The radical version of embodiment has specific benefits for this research. Firstly, the dynamical brain-body-environment coupling from the radial embodiment stand would be able to promote a more holistic understanding in education research since it does not confine learning to the mind solely. Secondly, to gain a deeper understanding of embodied cognition (i.e., the role of the body in learning), it is essential to explore how embodied cognition is influenced by and, in turn, shapes the relationship between individuals and their specific contexts (Danish et al., 2020). Thirdly, the sociocultural embodiment theory is also highly important in this situation, which pays more attention to the contextual impact on human perception. In this case, radical embodied cognition could also better aid the integration of social embodiment. Therefore, a radicle embodiment that takes the context as an integral part of the cognitive process could better facilitate the exploration of the interrelation between mental process, body, and environment in this study.

2.6.3 Perspective of Sociocultural Context in this Research

Based on the above discussion, the exploration of metaphors acknowledges the role of context in the metaphor production process. Moreover, the employment of a radical version and social embodiment also requires integrating the body’s environment. According to the discussion in the last section, the radical version of embodiment highlighted the role of the environment in the cognition process. The environment here, not only includes the physical environment that can generate directly embodied experiences but also the non-physical environment, the sociocultural context that students are situated within. These make it inevitable to consider the definition of sociocultural context and how it impacts the scientific learning process.

As Gazdar (1979) notes, a simply explicit definition makes it able to see inconsistencies or contradictions that were not visible before. For the definition of context, Duranti and Goodwin (1992) argue that defining context is inherently complex and cannot be captured by a single, precise definition due to its multifaceted nature. They acknowledge the importance of context and the ongoing efforts to understand it. They suggest that context involves a fundamental relationship between two key components: (1) the focal event, which is the phenomenon being contextualised, and (2) the field of action, which is the environment or setting in which the focal event occurs. The interplay between these two elements—where each informs and shapes the other—is central to understanding context. This relationship is analogous to the interaction between the organism and the environment in cybernetic theory (Bateson, 1972).

In the domain of science education, this definition has been widely adopted (Gilbert et al., 2011). It posits that the scope of context must encompass a certain behaviour, the environment in which this behaviour occurs, and the broader cultural setting in which this environment is embedded. This interpretation aligns closely with theories of embodied experience. The synthesis of the first two elements corresponds to the definition of embodied experiences within the radical embodiment theory, while the remaining cultural setting is the focus when examining the impact of the sociocultural context in this study. Thus, the scope of the sociocultural context in this research is the broader sociocultural setting in which the physical environment of the embodied experience is situated.

For interpreting this sociocultural context, one of the theories that can be used is Vygotsky's sociocultural theory, which considers the relationship between context and cognition. This provides a solid foundation for exploring the role of embodiment in social interaction (Vygotsky, 1934). Vygotsky emphasised the importance of situatedness in developing higher mental functions. In his framework, human cognition arises from the interplay of sociocultural and biological factors, with cognition emerging through the developmental interactions of human bodies with both the material and sociocultural world. As Vygotsky (1978) notes, "Every function in the child's development appears twice: first, on the social level, and later, on the individual level" (pp. 56). His insights into how cognition and social context interrelate can enhance the (primarily) individual-focused perspectives found in phenomenological and ecological traditions (Lindblom, 2020).

For the relationship between context and learning, Vygotsky's sociocultural theory offers a pivotal framework that views learning as part of the sociocultural process, with social interactions and cultural tools playing a mediating role in the construction of concepts and the learning process. The context in this case includes a serious of framework of social relationships and cultural milieu, including social interactions, cultural context, language and so on.

This theory also underscored the interconnection between language and thought. It serves not merely as a tool for communication but also as the scaffold for understanding and constructing knowledge. For science education, students' views on learning science have been found to align with Vygotsky's socio-cultural perspective, emphasizing the co-construction of knowledge through collaboration and experiential sense-making of scientific concepts (Mohammed and Kinyó, 2022).

The emphasis on of the role of sociocultural context and language in the cognition process makes Vygotsky's sociocultural theory suitable for this study. On the one hand, it can support integrating sociocultural context into the investigation of embodiment. On the other hand, it can also support the research design that uses language phenomena metaphors to explore conceptual understanding. Therefore, for this study, the analysis of context factors employed in this theory focuses on discussing how metaphor use and students' understanding of scientific concepts developed within the specific context of Chinese science education.

Drawing upon Vygotsky’s sociocultural theory, except for language, there is also one important source domain for students to construct metaphors: symbols. In his definition of symbols, Vygotsky detailed how signs and symbols contribute to the development of attention, abstraction, language, memory, numeric operations, and reasoning. Symbols are considered essential for representing and communicating knowledge, and they are integral to the development of concepts and meaning elaboration (Rabaglia et al., 2016). It serves as the psychological tool in Vygotsky’s framework, functioning as an abstract entity for communication and cognitive organisation within social interactions. Symbols, in this case, include linguistic symbols, such as words and written language, as well as non-linguistic symbols, such as mathematical notations and iconic representations (Hasyim and Reyes, 2022). Therefore, the source domain in this study may include idioms, religious icons, colloquialisms, or other expressions unique to a particular culture. Each represents the tangible manifestations of symbols.

Employing this theory for analysing source domains and sociocultural context factors, it aims to delve into how sociocultural context factors influence the source domains of metaphors and assess their role in students’ comprehension of scientific concepts. Such a classification not only mirrors Vygotsky’s theory of psychological tools but also offers a systematic framework for understanding the construction and function of metaphors across different sociocultural contexts.

2.6.4 The Relationship between Metaphor, Embodiment, and Context

As mentioned above, to investigate the relationship between embodiment, context, and students' understanding of scientific concepts, this study employs metaphor as an instrument for exploration, and CMT will be used in this research to construct a foundational theoretical framework to explain how students' thinking is intertwined with the metaphors they employ, as well as their embodiment and context factors. In this area, as mentioned in Section 2.4.3, there are still debates about how embodiment and context functioned together in the metaphor creation process. Therefore, for this research, it is essential to first clarify its perspective on the relationship between embodiment, culture, and metaphor.

There are two prevailing perspectives regarding the interplay between context and embodiment in the formation of metaphors. The first, cultural filtering, posits culture as a modulator, filtering universal human experiences through socio-cultural particularities to shape metaphorical expressions. This view maintains embodiment as the foundational underpinning of human cognition, where culture selectively elaborates and conventionalises embodied experiences into metaphors. The second viewpoint in the debate on the role of culture in CMT emphasises that context does more than shape embodiment—it directly influences metaphor creation and understanding. It posits that metaphors emerge from the rich interplay between cultural stories and physical experiences, with each culture crafting its own distinct metaphoric expressions. Here, culture is seen not just as a backdrop for experiences but as an active agent influencing metaphorical thought. The stance recognises that while bodily experiences form the base for metaphors, cultural context provides the specific nuances that define them.

Regarding this issue, this study will adopt the second perspective which aligns with Ibarretxe-Antuñano and Kövecses's arguments that conceptual metaphors are motivated by both embodied experiences and their sociocultural background. Firstly, this is because, although this research plans to employ CMT to investigate students' understanding of scientific concepts, its primary focus remains within the field of science education. Such a perspective may avoid over-focusing on cognitive linguistics in the study at the expense of the research focus and also provides greater avenues to uncover cultural aspects in the understanding of scientific concepts. Secondly, the educational environment is relatively more complex. Students' understanding of scientific concepts may be shaped by many contributing elements. Therefore, a more open attitude should be adopted when analysing students' metaphors, and it is not appropriate to ignore the effect of any particular factor as context is a pivotal research subject in this investigation. Thirdly, this perspective aligns with the body-environment-cognition loop discussed of radical embodiment adapted in this research.

The next question that needs to be addressed is how to identify embodiment and contextual factors in metaphors. The aforementioned points that when investigating metaphors, image schema is considered a useful tool since it is closely connected with embodied experiences. However, both the use of the image schema and the claims of moderate embodied cognition adopt a decontextualised approach to treat embodied cognition. For this research, however, its aim is more concerned with how embodiment and context collaboratively facilitate the generation of metaphors. Additionally, as mentioned above, this research will not adopt the bottom-up analytical approach from linguistic metaphor to conceptual metaphor. Therefore, the image schema will be difficult to employ as a tool to investigate embodied experiences and context.

According to the argument in Section 2.1.3, the identification of embodiment and cultural factors in metaphors could be achieved by identifying a metaphor as a universal or culture-specific metaphor. For universal metaphors, compared to culture-specific metaphors, its generation is mostly based on physical experiences. An important characteristic of universal metaphor is its source domain since only the source domain derived from everyday sensorimotor experiences has the potential to become universal. The other metaphors are culture-specific metaphors, including metaphors whose source domains are culture-specific embodied experiences or concepts/symbols proposed by Vygotsky. Following this standard, in this research, all metaphors could be categorised into two kinds: universal and culture-specific based on whether its source domain derives from everyday sensorimotor experiences or not.

This approach is consistent with the discourse presented in Section 2.4.4, which articulates that in science education, the characteristics of the source domain of metaphors significantly influence students' learning outcomes. This highlights the critical need to examine how embodiment and cultural factors shape the source domains of the metaphors students utilise to grasp scientific concepts.

2.6.5 A Refined Theoretical Framework for This Research

The foregoing discussion has delineated the theoretical stances that underpin this study, examining the diverse viewpoints related to embodiment, context and conceptual metaphor theory. This section will endeavour to synthesize these insights, providing a summative overview and theoretical framework for this research.

How we make sense of things and conceptualise them has always dominated cognitive research. Within the realm of cognitive linguistics, metaphors have been recognised as tools that shape our understanding of the world, influenced by the speakers' perceptions (Tang et al., 2017). Metaphors are thus interwoven with complex mental operations, paving the way for the investigation of cognitive processes through their usage. In the context of understanding scientific concepts, CMT provides a framework for examining how metaphors facilitate this understanding. CMT posits that the source domain of metaphors—representing the foundational element from which metaphors are drawn—plays a critical role in the generation of metaphors and significantly impacts the learning of scientific concepts. This research aims to investigate the influence of students' employment of the source domain in metaphors on their grasp of scientific concepts. The focus of the source domain also aligns with the longstanding stress about the source provided for students' science learning.

Moreover, CMT posits that abstract aspects of a target concept are mapped onto the concrete features of a related concept, suggesting that abstract ideas metaphorically inherit the properties of more tangible, concrete concepts (Lakoff and Johnson, 1980a). In this process, embodied experiences serve as the source domain and provide plentiful resources for metaphor emergence, and abstract concepts are the target domain that needs to be understood. When there is a similarity between these two domains, the metaphor will be constructed, which could enable us to interoperate the abstract concepts through the characters of concrete, physical concepts (Kövecses, 2020). This claim dovetails with the view of embodied cognition, both of which emphasise the role of bodily experience in conceptualisation.

As Johnson (1997) points out, while the physical configuration is important for embodiment, it depends on context as well. Regarding the emergence of metaphors, according to the extended version of CMT, context factors have also been found to be a significant contributor. The generation of these metaphors not only relies on our bodily experiences but also on the context it is situated. However, what role each of these two contributes and their relationship in the process remains to be further clarified. As mentioned in 2.5.3, regarding this issue, this study will adopt Ibarretxe-Antuñano and Kövecses's perspective that metaphors are motivated by both embodied experiences and their sociocultural background, as context is a pivotal research subject in this investigation. Therefore, the embodiment and context will both be considered important contributors to the conceptualisation process and impact metaphor production individually. This aligns with the aims of the current study, ensuring that both embodied experiences and context are afforded comprehensive exploration. Building on these arguments, the exploration of metaphors within this study will be conducted through the identification of universal and culture-specific metaphors, given whether their source domains are derived from everyday embodied experiences or not.

In examining the aspect of embodiment, this study adopts a radical perspective on embodiment, emphasizing the importance of the situated environment as an inseparable component of advanced cognitive processes. Moreover, this study also combines the perspective of social embodiment to fix its neglect that environment also includes the sociocultural environment, not only the physical environment. This combination posits that embodied experiences arise from the ongoing interactions between the human body and its physical, social, and cultural surroundings. Therefore, the investigation into students' use of the source domain for metaphor construction of scientific concepts within this study is not limited to the analysis of decontextualised image schemas. Instead, it also includes a consideration of the specific environments in which students learn, acknowledging that these contexts significantly shape the embodied experiences that inform their conceptual understanding. For embodiment factors, it is reflected in the embodied experiences in source domains students used to generate metaphors related to scientific concepts. The culture factor will be analysed according to Vygotsky's sociocultural theory.

For conceptual learning of scientific concepts, the above discussion in Section 2.3.1 and 2.3.2 highlights the significance of recognising intrinsic properties in the learning of scientific concepts. And also, as shown in Section 2.3.3, misconceptions play an important role in the investigation of students' conceptual understanding. This research aims to delve into how the use of metaphors affects students' comprehension of scientific concepts. It will further analyse the impact of the source domain of metaphors—shaped by embodiment and cultural factors—on students' understanding of the intrinsic or properties of scientific concepts, as well as how it is linked with misconceptions. This involves examining the interplay between the embodied and cultural experiences that inform the source domain and how this influences students' conceptual understanding of the fundamental nature of scientific concepts.

This refined framework is like a bridge connecting the field of CMT, embodiment and context, and will serve as the reference for research design and data analysis in current research.

2.7 Research Question and Sub-questions

As presented in Chapter 1, the main research question of this research is:

> How are students' understandings of scientific concepts related to their embodied experiences and sociocultural context?

Grounded in the preceding literature review and theoretical framework, this study will employ metaphors as the investigative tool. Pursuing this methodological path, the research will address two primary issues. The first concerns the nature of metaphors—universal or culture-specific—utilised in explaining scientific concepts. The second examines the correlation between the use of these metaphor types and students' conceptual understanding. These issues therefore generate two further research sub-questions:

1. What types of metaphors, universal or culture-specific, do students employ for scientific concepts?
2. Is there a correlation between the types of metaphors and students' understanding of scientific concepts and if so, how they are related?

3 RESEARCH DESIGN, METHODOLOGY AND METHODS

The preceding chapters have explored various arguments within the traditional and expanded views of CMT, focusing on the emergence of conceptual metaphors and their representational mechanisms. This ontological and epistemological interpretation of conceptual metaphors undoubtedly shapes the research design related to these investigations. Additionally, these chapters have examined the nature of the problem addressed in this dissertation, formulated the research questions, and established the frameworks for this exploration.

This chapter details how these theoretical insights are incorporated into the design of the current study. It begins by presenting the research paradigm and the overarching research design. Following this, it delves into the specific context of the research and its participants. It also describes the instruments used for data collection and the methodology of data acquisition. The chapter then outlines the data analysis procedures. Finally, it addresses the ethical considerations pertinent to this study and discusses the resolutions to these concerns.

3.1 Research Paradigm and Design

Research paradigms serve as crucial navigators for researchers throughout the empirical research journey, guiding everything from establishing the research aim to choosing data collection methods and, ultimately, analysing data and presenting findings (Abell and Lederman, 2007). According to Hussain et al. (2013), this is particularly important in education, where the choice of research paradigm can significantly impact the outcomes and implications of the research.

This chapter delineates the research paradigm that underpins the design of this study. Sections 3.1.1 and 3.1.2 introduce and discuss the rationale behind employing two key methodological approaches: the elicited metaphor analysis approach and the mixed methods research approach. Section 3.1.3 then details the specific research design adopted for this study.

3.1.1 Elicit Metaphor Analysis

Metaphors hold an important place in educational discourse, serving three potential functions. Firstly, metaphors facilitate the explanation of concepts and theories within specific subjects. For instance, in physics, metaphors are employed when electricity is conceptualised as a fluid or when electrons are likened to planets orbiting in a solar system (Wan and Low, 2015). Secondly, metaphors are instrumental in language learning, particularly in acquiring a vast array of idioms and figurative language in foreign languages (Littlemore and Taylor, 2014). The third function, however, delves into how metaphors can elucidate, critique, and potentially reformulate the various facets of education, teaching, and learning. This involves not merely identifying metaphors present in educational content but exploring metaphors that represent education itself. As elaborated in Section 2.4, metaphors have traditionally been recognised for their linguistic function, serving as a vehicle for expressing complex human thoughts. CMT goes beyond this linguistic field, offering a method for exploring into an individual’s conceptual system. This is accomplished by examining the process of source domain mapping to target domains, which is essentially the cognitive act of understanding one entity in terms of another (Littlemore, 2016). Within the realm of education, this interpretation of metaphor proves to be exceedingly useful, as it aids in fostering comprehension and facilitating learning.

This research primarily focuses on the third function, aligning with the perspectives of CMT. It posits that engaging in metaphorical thinking enhances awareness, enabling individuals to clearly articulate their beliefs (De Guerrero and Villamil, 2002; Low and Cameron, 1999). Over the past few decades, substantial research has utilised metaphor analysis to explore teachers’ conceptualizations of schools, teaching, and the curriculum (Cibulskienė, 2023; Korur and Sözen, 2019). Metaphors have been employed as a cognitive instrument to access and interpret the beliefs held by both students and teachers (Fang, 2015). This analytical approach has found widespread application among language educators and within the theories of language learning (De Guerrero and Villamil, 2002). Furthermore, metaphor analysis has proven effective in uncovering and understanding the various notions of teaching within the context of higher education (Bager-Elsborg and Greve, 2019). In these studies, metaphor data can be derived from either spontaneous 'free' discourse, such as when a teacher discusses an aspect of teaching with a friend or researcher, or from responses to various prompts specifically designed by the researcher to elicit metaphors (or to further explore previously provided ones). Many studies incorporate both 'naturalistic' spontaneous data and prompted elicited data (Cortazzi and Jin, 1999).

The metaphor analysis approach was employed in this research for two reasons. Firstly, this method has been well-established in various research settings since the early 1980s and has also been proven valid to reveal deeper thoughts and uncover participant conceptualisations (Lakoff and Johnson, 1980b). Metaphor is also a conducive instrument in terms of scrutinising linguistic expressions applied to communicate scientific concepts for the purpose of education (Johann et al., 2020). Secondly, based on the theory of cognitive linguistics, the emergence of metaphor is also profoundly relevant to embodiment and its context (Kövecses, 2020). These two reasons make metaphor analysis a valuable method for this research.

Within this line of research, this study design is based on the rationale for *elicit metaphor analysis* discussed by (Wan and Low, 2015). The methodological approach referred to as “elicited metaphor” involves the intentional prompting of a respondent by a researcher to generate a metaphorical expression or proposition. This prompt can be delivered linguistically or visually. During this process, the respondent is made explicitly aware of the nature of the request, with the researcher often employing directive language, including terms such as “metaphor”, “analogy”, or “comparison” to ensure clarity of intent. This technique is designed to produce a form of linguistic metaphor in which the target domain is openly stated by the respondent, thereby eliminating the need for the researcher to interpret it independently. The subject of the metaphor is either presented directly in the prompt (for example, consider Gravity as...) or is immediately accessible from the context of the communication, such as when it has been previously mentioned and is merely elided, or when a visual cue like a pointed-to picture is present. The majority of research in this area traditionally employs verbal formulations structured as ‘A is B’, or ‘A is like B’. However, a broader range of expressions is permissible and can be beneficial, encompassing other comparative constructs such as ‘A resembles B’, or ‘A can be compared to B’.

This elicited metaphor methodology might face scrutiny based on the question of why researchers don’t simply directly ask learners about their preferred teaching methods, inquire into teachers' perceptions of their roles, or observe learning situations in action. However, the approach is particularly advantageous in the following scenarios: when participants may lack an understanding of the theories or methods of interest to the researcher, and thus are unable to engage in discussion about them; when there is a risk that participants might offer responses they believe the researcher desires, commonly known as 'the party line'; when the topic has not been critically considered by the participants, leaving them with little to no preconceived responses; and when the participants are so familiar with—or disinterested in—the topic that a novel approach might stimulate a fresh perspective and re-engage them in the subject matter. This method, therefore, serves to elicit more authentic and reflective responses by circumventing these potential issues.

In this investigation, the use of elicit metaphors analysis is appropriate for probing into students' comprehension of scientific concepts. The first advantage is due to the nature of the metaphor. It can uncover the foundational source domains upon which students draw, domains that are frequently embedded with their physical experiences and the cultural contexts they inhabit. These underlying domains act as conduits, offering insights into the profundity of students' conceptual understanding. When students employ metaphors derived from everyday experiences or tangible phenomena to articulate their perception of more intricate concepts, such insights can afford a fresh outlook on their cognitive engagement with the material. The diversity of metaphorical source domains applied to various concepts may reflect the extent to which students have understood these scientific concepts.

Additionally, in instances where students find certain concepts monotonous or alien, their recourse to metaphors that appear disconnected may suggest a nascent attempt to reconcile these concepts with more familiar grounds, thus deepening their conceptual grasp. Consequently, this metaphorical strategy not only encourages students to describe concepts from a new perspective but also facilitates researchers in understanding the cognitive mechanisms and cultural influences that shape their scientific understanding.

3.1.2 Mixed Methods Research Design

Although there are a variety of ways to classify research paradigms, in the context of science education, two are particularly prominent. The first is the positivist/post-positivist paradigm, which describes as any approach that adopts the scientific method to study human actions, typically employing quantitative methods (Schwandt, 2001). The second is the interpretive paradigm, where the emphasis is on understanding the contextual meanings of human experiences, generally through qualitative methods (Moss, 2017; Taylor et al., 2012).

Apart from these two types of research, the rise of mixed methods research has been so rapid that it is often referred to as the third methodological movement, the third research paradigm, or the third path (Johnson et al., 2007; Teddlie and Tashakkori, 2009). In this context, its definition aligns closely with that from the inaugural issue of the Journal of Mixed Methods Research, which defines mixed methods research as “research in which the investigator collects and analyses data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study or program of inquiry” (Tashakkori and Creswell, 2007, p. 17).

Employing mixed methods research provides a multifaceted approach that enriches scholarly inquiry by incorporating diverse perspectives, thereby deepening our collective comprehension. It encourages us to embrace various perspectives of the world and to collaboratively interpret these diverse viewpoints. This collective approach enriches our understanding and discourse concerning the world and our role within it. Neopragmatists have written at length about the value of utilising mixed methods and the necessity of not being limited to a single, rigid method, as postpositivist thinkers have often characterised the scientific method (Maxcy, 2003). Instead, they advocate for mixed methods as a practical resolution to the ongoing debate in the research community regarding the employment of quantitative versus qualitative methods.

Mixed methods research is not merely a methodological approach but represents a distinct research paradigm with its own foundational perspectives on social reality which guide research and assumptions which inform the design and conduct of research. It embodies unique ontological and epistemological positions that set it apart from purely quantitative or qualitative frameworks. The philosophical orientation most often associated with mixed method is pragmatism (Biesta and Burbules, 2003), which is described as:

> "a deconstructive paradigm that debunks concepts such as "truth" and "reality" and focuses instead on "what works" as the truth regarding the research questions under investigation. Pragmatism rejects the either/or choices associated with the paradigm wars, advocates for the use of mixed methods in research, and acknowledges that the values of the researcher play a large role in interpretation of results." (Tashakkori and Teddlie, 2003a, pp. 713)

Pragmatism allows researchers to choose methods or combinations of methods that are most effective for answering their research questions (Johnson and Onwuegbuzie, 2004). The value of research should be judged based on its effectiveness, rather than its correspondence to a true condition in the real world (Maxcy, 2003). This effectiveness is assessed by the results' ability to address the specific problem the researcher aims to resolve (Mertens, 2015). This interpretation can be loosely explained as whatever the research methods and the resultant data—whether numerical or qualitative—are considered valid as long as they effectively address the research objectives, questions, or problems. Therefore, the direction of the research is dictated by the research question itself.

This paradigm offers unique values that distinguish it from positivism and interpretivism. Clark (2017) contends that the purpose of mixed methods research is to glean a more profound understanding of a research topic or problem than could be achieved using quantitative or qualitative methods alone. Fetters and Freshwater (2015) suggest that the synergy created by integrating quantitative and qualitative methods surpasses the simple sum of these parts, proposing an analogy where '1 + 1 = 3' (p. 116). Clark (2017) observes that mixed methods research can provide insights into, and explanations of, the processes inherent in a phenomenon and the multifaceted views it presents (p. 61), thus enhancing the utility and trustworthiness of the findings and even allowing for the discovery of unexpected results.

Furthermore, mixed methods possess intrinsic value when researchers aim to address problems within complex educational or social contexts (Teddlie and Tashakkori, 2009). Greene posits that the mixed methods approach to social inquiry holds the potential to emerge as a distinct methodology, honouring the varied traditions of social science because it encompasses multiple paradigm traditions (p. 20). This approach is considered to provide a more comprehensive and nuanced understanding of phenomena compared to single-method approaches. It achieves this by effectively balancing specificity with generality, ‘patterned regularity’ with ‘contextual complexity,’ and integrating both emic (insider) and etic (outsider) research perspectives. By focusing on the entirety as well as the individual components, and analysing the causes and effects, mixed methods research can offer a complete portrayal of the complex social phenomena under study.

The primary reason for employing mixed methods research is to address research questions that necessitate both quantitative and qualitative data for comprehensive answers. It is suggested that hybrid questions like ‘what and how’ or ‘what and why’ are strong mixed methods research questions and require both numerical and qualitative data (Creswell and Tashakkori, 2007). In this study, as mentioned in Section 2.7, there is one main research question, *How are students’ understandings of scientific concepts related to their embodied experiences and sociocultural context?*, and two sub-research questions:

1. What types of metaphors, universal or culture-specific, do students employ for scientific concepts?
2. Is there a correlation between the types of metaphors and students' understanding of scientific concepts, and if so, how they are related?

To address these research questions, a qualitative research approach is essential for uncovering students' embodied experiences, examining their sociocultural contexts, and analysing their conceptual understanding. A fundamental goal of qualitative research is to explore the participants' views of the situation being studied (Dornyei, 2007). It could provide a window into the unique ways individuals construct metaphors, showing how these are rooted in their tangible experiences and cultural settings, as well as the differences among different concepts.

In parallel, quantitative methods can be used to find theoretically based patterns in empirical material (Liljestrand et al., 2015). The use of statistical methods can help identify the prevalent patterns of these metaphorical source domains, exploring the connections between these source domains, embodied experiences, and sociocultural contexts. The combined use of qualitative and quantitative methods not only exposes the intricacies of metaphor formation by students but also outlines the overarching patterns within this process, offering a comprehensive and insightful cognitive framework for understanding.

Moreover, the combination of quantitative and qualitative methods can be used to identify and analyse patterns in textual data, allowing for the discovery of detailed patterns distinguishing entities, actions, attributes, and their relations (Montes-y-Gómez et al., 2002). For this research, the main resource for investigation is students' metaphors, therefore this combination enables interpretively linking qualitative and quantitative data sets and the transformation processes of qualifying and quantifying (Sandelowski, 2000) is particularly important.

Thus, this study employs a mixed methods research strategy, combining qualitative and quantitative approaches, to comprehensively understand how students construct metaphors and the influence of their sociocultural contexts and embodied experiences on their conceptual understanding of scientific concepts.

3.1.3 Research Design

The previous section explored the paradigmatic stance and advantages of employing mixed methods research, particularly highlighting its efficacy in navigating the intricacies of educational studies. It shows how mixed methods research transcends the limitations of traditional research approaches by leveraging the strengths of both qualitative and quantitative methods. This balanced approach enables a more nuanced exploration of complex phenomena, fostering a richer, more comprehensive understanding. This section delineates the integration of mixed methods research within the research design, synthesizing it with the elicited metaphor approach as detailed in Section 3.1.1.

Greene (2007) comments that different mixed methods research designs serve various research purposes, such as hypothesis testing, understanding, explanation, and democratisation. Creswell (2011) describes potential variations, like parallel (concurrent) designs that are either explanatory (qualitative data are collected after quantitative data to explain the quantitative results) or exploratory (qualitative data collection precedes quantitative data collection to explore a phenomenon). The stages at which mixing occurs in mixed methods research can differ, such as during data collection, data analysis, or throughout all stages of the research. These designs can combine different data types (numerical and qualitative) to answer research questions and also convert data (Bazeley, 2006). Specific mixed methods approaches are defined by the sequence of applying quantitative and qualitative methods (simultaneously or sequentially) and the stage at which the mixing of methods happens. Qualitative and quantitative data collection can occur in parallel or sequential forms. It is crucial to have a valid justification for the chosen sequence and design when conducting mixed methods research.

In this study, the elicited metaphor analysis approach is intended to serve as the foundational method for research design, with metaphors being utilised as the primary investigative tools. The rationale for employing a mixed methods research design lies in its potential to enhance the understanding and analysis of the metaphors elicited from students. Therefore, the mixed aspect of this research does only refer to the use of different types of data; rather, it pertains to the dual approach of data analysis—qualitative and quantitative.

Moreover, in metaphor analysis approaches, it is problematic to assume that respondents’ actions are solely guided by the thought patterns and understandings inferred from their metaphorical language. Their metaphorical accounts can be partial and/or conflicting (Low and Cameron, 1999). This highlights the need for a third, follow-up or monitoring stage in data analysis, such as conducting face-to-face interviews (Wan et al., 2011). This also requires the integration of qualitative interviews for more detailed analysis.

The foregoing indicates that an elicited metaphor analysis approach necessitates a mixed methods research design. The sequence of initially eliciting data, followed by conducting interviews, underscores the need for employing sequential mixed designs. These designs can address exploratory and confirmatory questions in a chronologically prearranged sequence. For this study, the quantitative analysis of metaphor questionnaires was executed first, subsequently followed by qualitative interviews.

In summary, the research design is a cohesive integration of the elicited metaphor analysis approach with a mixed methods approach. The former provides the foundational guidance for this research, emerging from the theoretical framework developed in the last chapter, while the latter is employed to enhance the interpretation of the data.

3.2 Context and Participants

Participant selection is a critical aspect of education research, as it directly impacts the quality and validity of the study findings. According to Ahmad and Hussain (2017), the selection of participants in educational research is crucial for considering the diversity of participants in terms of demographics, educational backgrounds, and experiences to capture a comprehensive understanding of the educational phenomena under investigation.

This section provides a detailed account of the participant selection process, which is informed by the research design of this study. Section 3.2.1 outlines the specific criteria used to select participants. Section 3.2.2 provides a brief description of the context of the sample school. Section 3.2.2 describes the recruitment process undertaken to enlist them.

3.2.1 Participants Selection Criteria

In determining the participants for a mixed methods research study, it is crucial to reflect on the distinctive nature of mixed methods, which is rooted in the pragmatic paradigm. The aim is to garner a more expansive understanding of the research problem. The initial phase of participant selection involves identifying a sample group that is most suited to the research question at hand. This group should ideally provide rich, relevant insights into the phenomenon being examined, thereby contributing to a deeper comprehension of the subject matter (Ivankova et al., 2006).

This research is centred on examining the effects of specific embodied experiences and the surrounding sociocultural contexts on students' comprehension of scientific concepts in Chinese context. The principal objective is to conduct an in-depth exploration of the interplay between embodiment, context, and science education rather than to generate generalised findings. Consequently, purposive sampling is an appropriate approach for selecting participants. This method involves the intentional choice of individuals who can provide the most pertinent data for the study’s goals (Tanga and Nyasha, 2017). Additionally, the chosen sample group should possess characteristics that facilitate the effective probing of the research questions. There are multiple factors to consider in this process.

First and foremost, the sociocultural context is a crucial element of this research. Participants should share a similar sociocultural background, with which the researcher is also well-acquainted, to enable a nuanced and insightful analysis. Secondly, as the study involves metaphor exploration and data collection methods such as paper-and-pencil questionnaires and face-to-face interviews, it is essential that participants possess adequate literacy, writing, and oral communication skills. Lastly, feasibility must be taken into account; the selected participants should be willing and able to commit the necessary time and effort to complete the research activities and data collection process effectively.

In line with the established selection criteria, primary school students in China were identified as the ideal participants. Primary school students typically have greater availability and willingness to engage in study-related activities. Furthermore, students at the high school level or in higher education may have been more extensively shaped by formal schooling, which could obscure the fundamental influences of embodied experiences and sociocultural factors that this study aims to investigate. Therefore, primary school students are the preferred participants for this research.

The Chinese educational syllabus of primary school indicates that students typically acquire foundational literacy skills by Grade 3 when they are over 10 years old (Ruan and Jin, 2012). Consequently, the study will focus on students in Grade 3 and above, ensuring that all participants have the requisite literacy capabilities to engage with the research tasks.

After deciding on the sample group, the next step is determining the sample size, which is a pivotal step in the mixed methods research process (Collins et al., 2007). In mixed methods research, the sample size must ensure the generation of both qualitative and quantitative data and consider the trade-off between the breadth and depth of the required information (Creswell and Clark, 2017).

For qualitative samples, as Michael Quinn Patton (2002) emphatically stated, there are no fixed rules for sample size in qualitative inquiry because the size depends on several factors such as “what you want to know” and “what will have credibility” (p. 244). The most useful way to approach qualitative research sample size involves the concept of saturation, which occurs when adding more units does not result in new information for theme development. Saturation is the general rule for purposive sampling, whereas representativeness is the general rule for probability sampling.

As outlined in Section 3.1.3, this study adopts a sequential mixed methods design, which involves a data transformation process that enables quantitative analysis. Typically, qualitative research employs smaller sample sizes, limiting the transferability of findings to a constrained sampling frame. To facilitate the generation of quantitative data, and thereby enhance the scope of the information gathered, the sample size in this research will be larger than that commonly used in qualitative studies. To ensure ample data collection, all eligible participants from the selected sample groups within the primary school were invited to take part in the study.

3.2.2 Sample School Context

For reasons of practicality, the study was conducted in one primary school in the researcher’s hometown China from February 2022 to March 2022. The selected school is located in Weihai, Shandong, a coastal city in eastern China. Weihai, known for its pleasant natural environment and living conditions. This school was established in 1983 and is the best primary school in Weihai now. Currently, the school has 26 classes, 93 staff members, and 1,310 students. The school’s high standard of teaching has been recognised by the Shandong Provincial Department of Education, earning titles such as *Shandong Model School* and *Weihai Specialty School*. These awards highlight the school’s excellence in educational quality and management.

The school offers a diverse curriculum that includes Chinese, English, Mathematics, Physical Education, Music, Art, and Martial Arts. In particular, the school places a strong emphasis on science education. From grades 1 to 5, all students attend science classes three times a week, with each session lasting 45 minutes. This focus on science education demonstrates the school’s commitment to fostering students’ scientific literacy and practical skills.

The student body primarily comprises children from Weihai and nearby areas, with no international students, and a nearly equal gender distribution. As a public school with no admission requirements, it enrols students with varying cognitive levels and abilities. Different from the UK, private schools are not as prevalent in China.

Therefore, most children in Weihai attend public schools, resulting in a highly diverse student background in this public primary school.

The school is equipped with modern teaching facilities, including well-resourced classrooms, laboratories, and a library, which support the comprehensive development of students across various subjects. Additionally, the school actively organises a wide range of extracurricular activities, including student clubs, sports competitions, and art exhibitions, aimed at promoting holistic development and enhancing students' overall competencies.

The data collected from this school can be seen as representative of primary education in Weihai and potentially similar coastal cities in eastern China. The study's findings can likely be generalised to other public primary schools within Weihai and potentially other similar cities in Shandong province. Given that public schools are the dominant form of education in China, and especially in Weihai, the findings can provide valuable insights into the public education system in this region since all the public school follow the same educational syllabus. While the study provides insights into the public education system in a specific region, generalising the findings to all of China should be done with caution. China is a vast country with significant regional differences in terms of economic development, educational resources, and cultural practices. However, the findings can still contribute to a broader understanding of primary education in urban areas of eastern China.

3.2.3 Participants Recruitment

The participant recruitment process was divided into three steps:

First, the permission of the headteacher to conduct the research at the sample school was obtained. An information sheet was provided to the headteacher, including the purpose and contribution of this research, as well as what kind of support the school hoped to provide (Appendix 7). With permission of the school, two teacher participants were selected first and recruited as navigators for student participants selection (Appendix 3). They can help the research by demonstrating endorsement of the project, building trust between the research team and the students and parents, and promoting potential participants' willingness to enrol in the study.

After identifying potential participants with the help of school teachers, an information sheet and consent form were provided to these students and their parents (Appendix 5 and Appendix 1). As the participants in this study are underage students, the researcher ensured that each potential participant was fully aware of both the information and its meaning in the two documents. A student becomes an official participant in this research only if signed consent forms are obtained from both the student and the parents.

Taking into account the students' readiness to participate, ultimately 480 participants were involved in this study across Grade 3, 4, and 5, including students aged between

9 and 14 years. This figure aligns with the recommendations of Borg and Gall (1979) regarding sample size, as well as with precedents set by prior studies in metaphorical analysis. The number of participants from each Grade group is listed below.

Table 3.1 Participant Number in Each Grade Group

Grade Group	Number of Participant
3 (10-12 years old)	163
4 (11-13 years old)	180
5 (12-14 years old)	137

3.3 Data Collection Approach

The research plan hinges on the utilisation of students' metaphors as the primary source for investigation. Consequently, crafting an efficacious data collection instrument to gather insights from the chosen participants is of paramount importance. Furthermore, in keeping with the mixed methods research approach of the study, the data collection strategy must be conducive to generating both qualitative and quantitative data.

In light of these perspectives, this section delineates the data collection procedures employed in this research. Section 3.3.1 provides a comprehensive description of the questionnaire, which serves as an investigative tool. Section 3.3.2 describes questions in the follow-up interviews. Section 3.3.3 outlines the process of how the data were collected from the participants.

3.3.1 Development of Metaphor Questionnaire

In research focused on metaphor analysis, two common methods are used to collect metaphors from informants. The first approach emphasises the spontaneous use of metaphors (also called spontaneous metaphors). These are collected from analogical statements that arise naturally in conversation or writing, such as in interviews and personal narratives. In the second approach, informants create metaphors through the completion of decontextualized, researcher-constructed prompts. These prompts typically adopt the two-domain structure of a metaphor, presenting the respondent with an ‘X is (like) Y’ formulation (e.g., Learning is like...); the results are elicited metaphors.

This approach has two clear advantages. Firstly, collecting elicited metaphors is generally more straightforward than identifying spontaneous metaphors in discourse data. This is because the researcher prescribes an explicit ‘X is (like) Y’ format, prompting informants to create metaphors in their responses. In contrast, gathering spontaneous metaphors from natural spoken or written discourse requires a substantial amount of data, as informants are often unaware of their metaphor use. Secondly, compared to the complexity of coding spontaneous metaphors in discourse data, the researcher in an elicited metaphor study typically pre-specifies the metaphor prompt format and contextual topic. Informants only need to provide the vehicle terms. The researcher’s task is to verify that the responses are metaphorical and exclude any non-metaphorical instances. A significant proportion of elicited metaphor studies use prompts involving part of a simile in an ‘X is like Y’ format (Villamil and de Guerrero, 2005), allowing respondents to construct their answers using similes.

Although identifying and collecting elicited metaphors requires relatively less effort than dealing with spontaneous metaphors, the elicited metaphor technique is not methodologically transparent. Some recent studies have reported unsuccessful responses to researcher-constructed metaphor elicitation tasks (Zapata and Lacorte, 2007). These issues typically involve instances where no answer was provided, no metaphor was used, or no explanatory reasoning was given to support the metaphor. Specific to this study, participants are primary students. Therefore, purposeful training sessions are necessary to help students complete the questionnaires efficiently.

Elicitation of metaphor could be finished through various forms. Data collection strategy decisions in mixed methods research should be guided by the research purpose and the paradigmatic belief systems of the research team (Greene, 2007). Onwuegbuzie and Johnson (2006) note that the strength of mixing data collection methods lies in leveraging the strengths of one method over another for a particular purpose. This research employed the questionnaire as the instrument for metaphor elicitation. Questionnaires have been regularly used to yield three types of data about respondents: factual questions to determine demographic characteristics, behavioural questions to understand actions and/or personal histories, and attitudinal questions to capture their thoughts (Dörnyei, 2003). This research aligns with the third strand.

Questionnaires offer several advantages over other research tools that can access similar types of data, such as interviews. The primary advantage is that they allow easy and swift access to information from a large population, thereby saving time for both respondents and researchers (Dörnyei, 2003; Munn and Drever, 2004). However, the effectiveness of questionnaires can be limited by the reading ability required to understand and respond to them. To address this issue, this study specifically selects participants who possess both reading and writing literacy. When literacy is not a concern, questionnaires are an extremely efficient data collection strategy.

Questionnaire items can be structured as closed-ended, open-ended, or a mix of the two, each format being suitable for generating data for quantitative, qualitative, or mixed methods research. In this particular study, the questionnaire was used to elicit metaphors from students, necessitating the use of open-ended questions. This aligns with the elicited metaphor approach, which is exemplified by prompts like ‘A is like __, because __’.

Every scientific disciplinary domain has a range of concepts and ways of discussing them that are considered authorised versions of scientific issues (Scott et al., 2007). The selection of scientific concepts is important for this study. This process was assisted by two primary science teachers from the participating school. All concepts were selected from Grade 1 and Grade 2 textbooks, ensuring all participants (including Grade 3, Grade 4 and Grade 5) had been formally taught at least once before the study. This is designed to make sure participants can finish the questionnaire during the data collection process.

The selected concepts are the Magnet, Concave Lens, Vapour, Mercury, Gravity, Buoyancy, Energy, and Circuit. The first four concepts selected are concrete concepts, possessing a physical form, while the latter four are abstract concepts. These concepts are all foundational and marked as essential concepts in the Chinese primary science education syllabus. Teacher participants in this study also mentioned that these concepts are important for primary school science teaching.

The finalised questionnaire, entitled My Understanding of Scientific Concepts (Appendix 8), was crafted in accordance with the aforementioned criteria and includes a blend of personal questions and metaphor elicitation prompts. The administration of this questionnaire is anticipated to uncover participants' developing conceptual understandings as they articulate their metaphors, drawing on source domains and their reasons for the comparisons made with these scientific concepts. It is structured into two distinct parts: the first gathers personal information from the participants, while the second consists of open-ended questions aimed at eliciting participants' metaphors that express their understanding of specific scientific concepts. For the personal information section, the focus is on capturing the demographic details of the participants. The subsequent metaphor elicitation section is designed to probe deeper into the participants' conceptual grasp of the selected science topics.

To ensure clarity and comprehensibility, two primary school teachers from China were consulted to review the questionnaire. Their feedback led to two revisions in the phrasing of the items. Then this questionnaire had a pilot test with 20 students from the sample school, during which no issues concerning the comprehensibility of the questionnaire items were reported.

3.3.2 Development of Follow-Up Interview Question

The reason for using interviews was that they could provide rich insights into what is in and on people's minds, including informants' experiences, opinions, aspirations, and feelings regarding predetermined questions or specific topics (Denscombe, 2017; Patton, 2002). As mentioned in Section 3.1.3, a follow-up interview is necessary to further investigate participants understanding. Therefore, in this study, there were three questions in the interview:

1. What do you think can impact the specific words you choose to describe your explanation?
2. For concepts in questionnaire, how do you build your understanding of it?
3. What challenges did you encounter when you answered the questionnaire?

For this first question, the rationale behind this inquiry is grounded in understanding the motivations and basis for students' use of metaphors. The choice of specific words by students when describing scientific concepts can be influenced by a myriad of factors, such as their prior knowledge, experiences, emotions, cultural backgrounds, and linguistic habits. This question can unveil the diversity and complexity within students' internal thought processes. Moreover, it aids in comprehending how students select words based on their understanding and interpretation of the world, which is pivotal for assessing the depth and accuracy of their conceptual understanding.

For the second question, this question investigates the internal processing mechanisms students engage with when confronted with scientific concepts. Students may construct an understanding of scientific concepts through various methods, including connecting new and old knowledge, employing concrete or abstract thinking, and even through bodily perceptions. Understanding this process assists educators in identifying effective teaching strategies, such as deepening understanding through practical activities or concrete examples. It also helps researchers discover how embodied experiences and contextual factors play roles in the process of conceptual understanding.

For the last question, the challenges faced by students in responding to questionnaires may reflect difficulties in understanding and applying concepts. These include comprehension and generation of metaphors, the abstract nature of scientific concepts, and the precision of linguistic expression. The design of this question is intended to help researchers gain a deeper understanding of the barriers students encounter in the process of conceptual understanding and how to adjust teaching strategies to help students overcome these barriers. Additionally, students’ responses could also reveal shortcomings in the questionnaire design itself, providing a basis for improvement in subsequent research.

Through these three questions, researchers can not only gather data on students’ metaphor usage habits but also gain insights into students’ cognitive processes and their relationship with educational practice.

One of the key challenges interviewers need to be aware of is what Denscombe (2017) calls the interviewer effect. Since an interview is essentially a conversation-based interaction between the researcher and the interviewees, the responses are likely influenced by the researcher’s presence (Gass et al., 2005). To address this, the study employed the interview skills suggested by Denscombe (2017) to improve the validity of the interviews.

The interview questions employed were open-ended, which allowed for the expansion or clarification of meanings, thus fostering a more natural dialogue between the interviewer and the participant. This approach also ensured that essential information was consistently addressed across all interviews (Bryman, 2004). However, a potential drawback is that interviews based on open-ended questions can easily devolve into informal conversations, with the discussion topics potentially straying significantly from the research aims (Holstein and Gubrium, 1995). To mitigate this, the researcher endeavored to keep participants focused on subjects pertinent to the research questions and interview objectives. Consequently, the interviews adhered closely to the pre-designed guides. Additionally, the researcher frequently repeated and paraphrased participants' comments to enhance comprehension and clarify contexts, which facilitated the transcription process.

3.3.3 Data Collection Procedure

Wan (2012) pinpointed three primary factors that contribute to the non-completion of tasks involving metaphor production: firstly, a lack of comprehensive knowledge about the nature and function of metaphors; secondly, an absence of clear understanding regarding the purpose behind generating metaphors; and thirdly, a deficit in the requisite academic writing skills necessary for such tasks. Wan further suggested that these challenges could be effectively mitigated through pre-elicitation training, which has the potential to significantly reduce difficulties encountered during metaphor production. In light of this, to lower the non-completion rates, it is advisable to conduct a training session before commencing data collection activities.

In accordance with the findings of Wan (2012), this research implemented a metaphor training session of 20 minutes, designed to equip the participants with the requisite capabilities to effectively undertake the metaphor elicitation task. This training session, facilitated by the researchers directly before conducting the questionnaire, was structured into three distinct segments. The session commenced with an introductory exposition on the concept of metaphors. Subsequently, the students engaged in practical exercises, creating metaphors linked to concepts that were personally familiar to them, with prompts such as ‘Mother is like __, because __’ or ‘Happiness is like __, because __’. For the culminating activity, the students were tasked with formulating metaphors for scientific concepts that were not directly examined in this research, such as ‘temperature’, thus affording them an opportunity to practice in a context that was relevant yet did not impact research results.

Following the completion of the questionnaire survey, students were presented with the option to partake in voluntary follow-up interviews. Participants from three grade levels chose to engage in further discussions. In detail, interviews included 47 students from Grade 3, 54 from Grade 4, and 44 from Grade 5. For management and discussion purposes, students within each grade level were organised into five subgroups, each participating in a focus group interview. These sessions lasted around 40 minutes, permitting thorough discourse and information collection while ensuring ample expression time for all participants. The process emphasised establishing an open and secure discussion setting, allowing students to share their thoughts and interpretations freely. The anonymised data will be utilised to delve into students’ metaphorical understanding of scientific concepts and the influence of embodied experiences and context on their conceptual cognition.

In agreement with the sample schools, all data collection procedures were scheduled during the students' free school period, which followed their regular school classes. This careful planning ensured that the research activities did not interfere with the standard school curriculum. Students who gave their consent to be part of the study were guided to a separate classroom allocated for conducting the research, whereas those who opted not to participate remained in their usual classrooms, engaging in their typical activities.

For data collection process, Grade 3 and Grade 4 Group had their data collected in February 2022. The data collection of Grade 5 Group occurred a month later, in March 2022.

Language precision is paramount in this study, especially given that any ambiguities stemming from transcription errors could significantly compromise the analysis of data. Every aspect of this research, from the design of the questionnaire to the participant's responses, was performed in Mandarin Chinese, embedded within the Chinese cultural milieu. To minimize the risk of misinterpretation, all data were initially analysed in Chinese. Then, to allow for a wider dissemination and a thorough review process, the results were translated into English and are to be presented in the final thesis in English. This bilingual method of data treatment guarantees the authenticity of the data while also enhancing its accessibility and comprehensibility on a global scale.

3.4 Data Analysis

In the analysis of elicited metaphors within educational research discourse, two primary methodologies are frequently employed, either independently or in conjunction: (a) the classification of participants' metaphorical language into broader conceptual categories as a means to deduce underlying metaphors, a method exemplified by Low and Cameron (1999), and (b) the scrutiny of metaphorical entailments that participants provide as justification for their chosen metaphors, often benchmarking these against the given source or vehicle term, a technique illustrated by Wan's work (2015). The objective of this research, however, diverges from merely summarising the students' collective understanding of the concepts under study. Instead, the focus is on an in-depth examination of how embodiment and context influence students' conceptual interpretations. The analytical lens is thus directed towards understanding why participants perceive scientific concepts to be akin to the entities they associate them with. Consistent with the theoretical underpinnings articulated in Section 2.6.1, this study adopted the second approach for metaphor analysis. It concentrates on the interpretation and coding of elements within students' metaphors, specifically targeting the source domain and the students' explanations for their metaphorical comparisons.

Content analysis served as the primary method for analysing metaphors in this study. This approach enables researchers to draw valid and replicable inferences about the meanings of texts within their usage contexts (Krippendorff, 2004). Qualitative content analysis, as defined by Glaser and Laudel (2019), involves a stringent and systematic set of procedures for the rigorous analysis, examination, replication, inference, and verification of written data (Krippendorff, 2004; Mayring, 2004). The exploratory nature of this research aligns with the principles of content analysis and the cognitive linguistics tenet that understanding language arises from its use. Additionally, in this sequential mixed methods design, data analysis integrates qualitative and quantitative strategies, ensuring they are combined, connected, and unified.

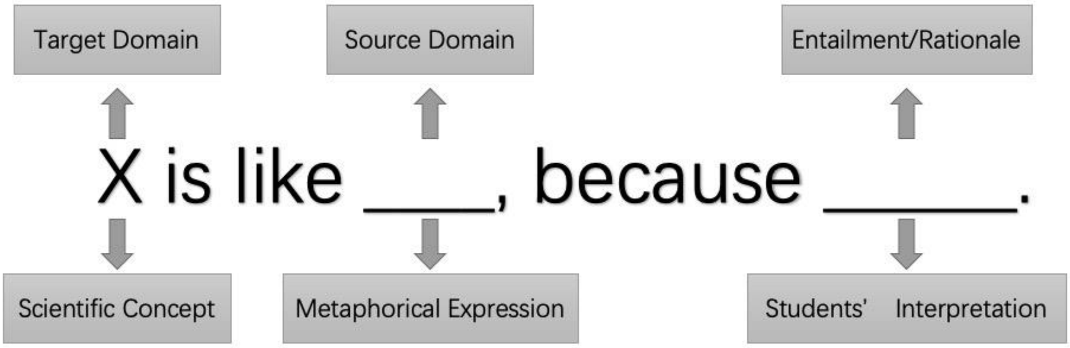
The first section of this chapter delineates the context for metaphor analysis in this research. Section 3.4.2 presents content analysis procedures for metaphor analysis and their application in this study. Section 3.4.3 details the specific steps involved in the analysis process, while Section 3.4.4 describes the internal reliability check conducted to ensure the robustness of the research findings.

3.4.1 Context for Metaphor Analysis in this Research

In the questionnaire, as mentioned before, a sentence is employed to elicit students' metaphorical expression: "X (a scientific concept) is like __, because ___." The first space in the sentence asked participants to create a metaphor about the scientific concept, and the second one required them to explain the rationale for their answers.

According to the conceptual metaphor theory, the mapping between the source domain and the target domain is derived from their partial similarity. In line with this argument, students' metaphor production process is based on their interpretation of selected scientific concepts, and this interpretation is then further expressed through the emergence of metaphorical expression. Therefore, for the sentence in the questionnaire, the second space following 'because' could reflect students' interpretation of given scientific concepts, while the first space could reflect how this understanding is expressed. This relationship is depicted in Figure 2, upon which the metaphor analysis in this research is predicated.

Figure 3.1 Data Analysis Rationale



3.4.2 Content Analysis Approach for Questionnaire Data

For conducting content analysis, Denscombe (2017) sets out a six-stage process:

1. Choosing an appropriate sample of data.
2. Breaking down text into smaller component units of analysis.
3. Developing appropriate categories for analysing the data.
4. Coding the units to fit the categories.
5. Conducting frequency counts of the occurrence of the units.
6. Analysing the text from the basis of the unit frequencies and how they relate to other units in the text.

The subsequent content delineates the execution and any necessary modifications of these procedures as they were applied for the questionnaire analysis in this research.

The first step involves selecting appropriate data. According to Glaser and Laudel (2019), the aim of qualitative content analysis is to transition from the original text to an analysis of the extracted information, concentrating on the meanings of texts and their components. Texts are defined as any written communicative materials intended to be read, interpreted, and understood by individuals other than the analysts (Krippendorff, 2004). In this research, the data comprises students' responses to their questionnaires. Krippendorff (2004) identifies several features of texts pertinent to content analysis, notably that texts do not possess objective, reader-independent qualities; instead, they bear multiple meanings and support various readings and interpretations. There is no singular meaning awaiting discovery or description within them. Consequently, metaphors are a suitable type of text for content analysis in this context.

The second step is breaking down text into smaller component units of analysis. Under the framework of Conceptual Metaphor Theory, each metaphor can be dissected into three distinct components: the source domain, the target domain, and the explanation. In the context of this research, the target domain was predetermined by the researcher. Students were tasked with completing the remaining two parts of their questionnaires, providing both the source domain and their explanation. These responses formed the basis of the subsequent analysis.

The third step in data analysis entails the creation of suitable categories for interpreting the collected data. In this study, the coding criteria were derived from prior related studies and the theoretical foundations laid out in Section 2.6. The analysis is concentrated on two main components: the analysis of the source domain and the explanation provided by the participants. For coding these two components, three stages of coding were established.

The first stage of coding is about whether students' answers are valid metaphors. A popular method Metaphor Identification Procedure Vrije Universiteit (MIPVU), an extension of MIP (metaphor identification procedure) developed by the Pragglejaz Group was used in this research (Nokele, 2014). However, some modifications to it are required. Amongst metaphor research focusing on the relationship between embodiment and culture construction, the linguistic data frequently used are mostly secondary data, including everyday language corpus (Ansah, 2014; Tramutoli, 2020), folk proverbs (Yu, 2003), Facebook comments (Zibin and Hamdan, 2019) and so on. Only a minority of studies employed methods such as group discussion (Ansah, 2013) for data collection. Whereas this research is more concerned with obtaining first-hand data from participants through questionnaires or interviews. Therefore, it employs the elicit method analysis for data analysis, in which metaphors are collected by providing participants with a prompt such as A is (like) B because ... (e.g. A teacher is like ..., because ...) (Cortazzi and Jin, 2020) and require them to complete this sentence through speaking or writing (e.g. interviews or personal accounts). In this way, the answer for the prompt is further developed into three parts: target domain (words provided to participants), source domain (participants' metaphorical expression), and entailment (the reason). Compared to other approaches, the metaphor identification process of this approach eliminates the selection of suitable metaphorical expressions from the complex corpus and can instead start directly with the judgement of participants' responses.

Therefore, after being adopted, the MIPVU approach in this research involved the following steps:

1. Read the entire answer to gain a general understanding of students' thinking.

2. Take into account the source domain and entailment to establish its contextual meaning.
3. For each source domain, determine: (a) If it has a more basic contemporary meaning in other contexts than the one in the given context, which tends to be more precise or historically older. (b) If the contextual meaning contrasts with the basic contemporary meaning but can be understood in comparison with it.
4. If the answer to both (a) and (b) is yes, then the answer can be viewed as metaphorical.

After these steps, all responses collected were divided into two groups based on whether metaphorical or not for further data analysis: Metaphor and Invalid answers. Only metaphors were analysed in the following step. Any response was regarded as failure if it did not meet either of the two criteria and would be excluded from the data analysis.

Following this step, all gathered responses were divided into two categories for subsequent analysis: those that were metaphorical were classified as Metaphor, others were classified as Invalid Answers. In the next phase of analysis, only the responses that qualified as metaphors were considered.

The second stage of coding relates to the first research question, which explores the variety of metaphors students employ to elucidate scientific concepts. This analysis was conducted on the metaphors' source domains, as they are crucial in this process. The coding criteria hinge on the distinction between universal metaphors and those that are culture-specific, as delineated in Section 2.6.4. A defining characteristic of a universal metaphor is its source domain, which stems from common sensorimotor experiences, thereby holding the capacity to be universally understood. Conversely, culture-specific metaphors emerge from unique cultural experiences or are rooted in particular cultural concepts, symbols, etc. Applying these parameters, this study classified all metaphors into two groups: universal and culture-specific. This classification depends on whether their source domains are based on commonplace sensorimotor experiences.

The third stage of coding pertains to assessing how explanations are linked to students' grasp of target domains, which, in this case, are the selected scientific concepts under study. This comprehension is mirrored in the students' explanatory content within their responses. There is a broad array of categorisations for students' conceptual understanding within the relevant literature. For instance, one study gauged the depth of student comprehension of the concept of diffusion by employing a modified version of the Concept Evaluation Scheme (CESCH), initially developed in prior studies, as depicted in Table 3.2 (Westbrook and Marek, 1991).

Table 3.2 Concept Evaluation Scheme (CESCH)

Conceptual Level		Categorising Criteria	Corresponding to This Study
1	Complete understanding	The student's response parallels a theoretical, scientific view of the concept.	Intrinsic Properties and Extrinsic Properties

2	Sound understanding	The student’s response is complete, but not molecular in nature. The response is concrete rather than theoretical.	
3	Partial understanding	The student’s response contains part, but not all, of the information necessary to convey either complete or sound understanding. No incorrect information occurs in the response.	
4	Partial understanding with specific misconception	The student’s response contains correct information, but also indicates a misunderstanding concerning some aspect of the concept.	Misconceptions
5	Specific misconception	The student’s response indicates a complete misunderstanding of the concept.	
6	No understanding	The student’s response consists of “I don’t know”, the question repeated, or irrelevant remarks. (No response to the CES was considered to indicate no understanding.)	Invalid Answers

In this study, these criteria were further revised to serve as a framework for coding students’ levels of understanding. The original CESCH delineates the first three levels as representations of students’ understanding, ranging from completely to partially correct in relation to the concepts. This pertains to the intrinsic and extrinsic properties previously discussed in Section 2.3, denoting attributes that are universally accurate or context-dependent, respectively. The subsequent two levels of the CESCH address scientific misconceptions, signifying an understanding that deviates from accepted scientific knowledge. The final level of conceptual understanding indicates responses that do not reveal any comprehension, akin to the Invalid Answers identified in the first stage of categorisation. As such, responses at this level are excluded from this phase of analysis. Based on these theoretical perspectives, the coding criteria in this step were constructed and presented in Table 3.3. The definition of intrinsic property is the property which is solely determined by the concept’s own nature, independent of any other nature or existence; all other properties are considered extrinsic (Littlemore and Taylor, 2014).

Table 3.3 Criteria for Categorising Students’ Conceptual Understanding

	Conceptual Understanding	Categorising Criteria
1	Intrinsic Properties	Understanding that describes the property which is solely determined by the concept’s own nature, independent of any other nature or existence; all other properties are considered extrinsic.
2	Extrinsic Properties	Understanding that describes the property which dependent on external conditions.
3	Misconceptions	Understanding that is in contrast with its explanation in science context.

Through these three coding stages, step four of the content analysis approach, Coding the units to fit the categories, was conducted.

The subsequent fifth and sixth steps, which entail conducting frequency counts of the units’ occurrences and analysing the text based on these frequencies, are geared towards the generation of quantitative data. As previously stated, metaphors in this research were analysed qualitatively and quantitatively. The qualitative component includes the examination of the content of metaphors, while the quantitative aspect involves analysing the data that are quantified through the process of metaphor coding. Following a thorough content analysis, the outcomes of the coding process can be employed to generate quantitative data. This quantifying may entail straightforward operations such as tallying the occurrence of specific themes or responses. Alternatively, it could involve more elaborate evaluations, such as assessing the intensity or prominence of these themes or responses, and more sophisticated inferential statistics. The selection of the appropriate method is contingent upon the specific research questions being addressed.

For the first question, ‘What types of metaphors, universal or culture-specific, do students employ for scientific concepts’ aims to explore and describe the metaphor type in students’ answers to questionnaires. The description analysis therefore can fit this purpose. Descriptive statistical methods include techniques for summarizing numeric data into easily interpretable tables, graphs, or single representations of a set of scores. The objective is to comprehend the data, identify patterns and relationships, and effectively communicate the results. These objectives are achieved through visual representations, such as images and graphs, and concise summaries that aid the reader in understanding the nature of the variables and their interrelationships.

Moreover, based on the participants and data collected in this research, the first question can be further extended to explore how these metaphor types are related to different grades and concepts. This question aims to explore the relationship. Much educational research is concerned with establishing relationships between variables. Correlational techniques are generally intended to answer three questions about two variables or two sets of data. In this research, since all data are non-parametric and do not adhere to a specific probability distribution, the chi-square test to test correlation is appropriate (McHugh, 2013). It can be applied to examine the relationship between categorical variables, such as the correlation between different teaching methods and student performance or the correlation between educational philosophies and teaching-learning conceptions (Durkaya and Lokumcu, 2022). The chi-square test is particularly useful when dealing with categorical variables in educational research, as it allows for the examination of associations and correlations between these variables without assuming a specific distribution for the data (McHugh, 2013). In this research, the association between metaphor types and variables such as grades and concepts were examined using the chi-square test.

The second question focuses on exploring correlations. Thus, after the coding of students' understanding was completed, the chi-square test was utilised to assess the correlation between the types of metaphors employed and the students' conceptual understanding of scientific concepts.

It should be noted that the quantitative analyses conducted here are limited to identifying the presence of a relationship between the factors in question. To elaborate on the nature of these connections, a qualitative description is also necessary. The manner in which these analytical approaches are integrated will be detailed in the next section.

3.4.3 Thematic Analysis for Interview Data

Thematic analysis, as described by Liamputtong (2009), is a method for identifying, analysing, and reporting repeated patterns of meaning across a dataset. This qualitative analytic method is extensively used in psychology and other fields (Braun and Clarke, 2006). Reflexive thematic analysis is one of several approaches to conducting thematic analysis. Braun and Clarke (2006) initially conceptualized reflexive thematic analysis as a paradigmatically flexible analytical method, suitable for a wide range of ontological and epistemological frameworks.

The reflexive approach to thematic analysis emphasises the researcher’s active role in knowledge production (Braun and Clarke, 2019). It reflects the researcher’s interpretive analysis conducted at the intersection of (1) the dataset, (2) the theoretical assumptions underlying the analysis, and (3) the researcher’s analytical skills and resources. Rather than aiming for accurate or reliable coding or seeking consensus among multiple coders, the reflexive thematic analysis focuses on “the researcher’s reflective and thoughtful engagement with their data and their reflexive and thoughtful engagement with the analytic process” (p. 594).

This makes the reflexive thematic analysis approach suitable for analysing interview data in this research, which involves student interviews that explore the reasons behind their use of certain source domains and their understanding of scientific concepts. The aim of the interviews in this study is not to find a unified or objective understanding but to explore and elucidate how participants constructed metaphors in the questionnaire and their understanding of scientific concepts based on their own experiences and knowledge. Moreover, by adopting this approach, a researcher can better incorporate the intricacies of the theories, such as embodied cognition and conceptual metaphor theory, while interpreting the data, providing a rich, theory-informed perspective on the students' interviews. These can all allow for an in-depth understanding of participants' metaphor production process.

In the reflexive approach, themes are not predefined to identify codes. Instead, themes are generated by organising codes around a core commonality or 'central organising concept' that the researcher interprets from the data. This approach captures significant aspects of the data related to the research question and represents a patterned response or meaning within the dataset.

Braun and Clarke's seminal paper marked a milestone for thematic analysis. This study adhered to the steps proposed by Braun and Clarke (2006) for processing data collected from follow-up interviews. These steps include familiarising with the dataset, coding, generating initial themes, developing and reviewing themes, refining, and writing up.

To prepare the data for analysis, the interview data were transcribed in the original Chinese to ensure more precise analysis. Following this, the researcher reviewed the transcripts, checking whether the generated themes aligned with the codes and modified the themes if necessary. This process was followed by identifying patterns within and across participants’ responses. To enhance the validity of the thematic analysis and mitigate the influence of researcher subjectivity, two Chinese primary school science teachers from the sample school were invited to recode the transcripts. Based on their suggestions, one change was made to the wording of the identified patterns.

3.4.4 Data Analysis Procedure

According to the criteria described in the last section, the analytical procedure of this research comprises four steps, aimed at investigating the effects of both embodiment and sociocultural factors on students’ comprehension of the scientific concepts proposed by two research questions (Section 2.7).

Step 1: Questionnaire and Interview Transcript

At this stage, all responses from the students’ questionnaires, which were originally completed using paper and pencil, as well as their answers in the interview were transcribed into a digital text format for subsequent analysis by the researcher.

Step 2: Conducting Coding

Following the coding criteria outlined in Section 3.4.2, the three-step coding process was applied to the text that had been transcribed in the previous stage.

Step 3: Metaphor Types Analysis

To address the first research question, the investigation commenced with a quantitative descriptive analysis to outline a general pattern in students' use of metaphors. Subsequently, a qualitative analysis provided an in-depth description of these metaphors. For universal metaphors, the focus was on scrutinising their source domains to understand the interplay between students' embodied experiences and their environments, pinpointing the embodied experiences that shape these metaphors. The analysis of culture-specific metaphors examined their source domains through the lens of Vygotsky's sociocultural theory, as detailed in Section 2.6.3.

Following this, a chi-square test was carried out to quantitatively determine whether there was a correlation between the metaphors used by students, their grades, and the scientific concepts. This quantitative measure was complemented by a qualitative description to further elucidate the nature of these relationships.

Step 4: Metaphor Types and Conceptual Understanding Analysis

Regarding the second research question, the initial step involved performing a quantitative chi-square test to examine the P value level of significance, and see if there was a significant relationship between the metaphors used by students and their conceptual understanding. This was followed by a comprehensive qualitative analysis aimed at interpreting and explaining the nature of this relationship.

Step 5: Follow-Up Interview Analysis

Following the coding criteria outlined in Section 3.4.3, the thematic analysis coding approach was applied to the interview data that had been transcribed in the previous stage.

Upon completion of all data analyses, during the thesis writing stage, all analysis results and examples were translated into English for clarity and comprehension. When citing participants' metaphors as examples, their identities were replaced with four-digit codes. The first digit represents the participant's grade level (from 3 to 5), the second digit represents the class number (from 1 to 8), and the last two digits are randomly assigned to distinguish between different participants in the same grade and class. For example, 4315 represents a participant from Grade 4, Class 3, and 4308 represents another participant from the same class.

3.4.5 Internal Reliability Check

Internal reliability in education research refers to the consistency and stability of measurements within a study. This is crucial for ensuring that the results obtained are dependable and can be replicated. The reliability of the interview data coding was addressed in the previous section; this section focuses on the questionnaire analysis.

To enhance the internal reliability of coding in education research, involving another person in coding and then comparing the results with the researcher can be beneficial. This process can improve the consistency and dependability of the coding. Olsen and Williamson (2015) highlighted the importance of improving coding reliability, suggesting that experience did not necessarily improve the reliability of coding across various systems. This implies that involving another coder for comparison can provide valuable insights into the consistency of the coding process. Additionally, Ogunrin et al. (2016) demonstrated the excellent test-retest reliability and internal consistency of an online module for ethics education, indicating the potential for improvement in reliability through collaborative coding and comparison. This suggests that involving multiple individuals in the coding process can contribute to enhancing the internal reliability of the research.

As discussed in Section 3.4.1, the qualitative coding of metaphor analysis in this study is structured into three segments: metaphor identification, distinguishing between universal and culture-specific metaphors, and classifying students' conceptual understanding. To enhance internal reliability, a primary science teacher was enlisted to code data related to a specific concept. This teacher was provided with a detailed set of coding criteria for each segment. Upon completion of the coding task, an interview was arranged to examine and understand any discrepancies between the coding outcomes of the researcher and the teacher. The coding results and the divergences pertaining to the selected research concept of 'Gravity' are documented below.

Part 1: Metaphor identification

For the first part, all the coding results amongst the researcher and the science teacher were the same except for two, which are listed below.

Table 3 4 Differences in Coding Results of Part 1

	Answer with Different Coding Results	Researcher	Science Teacher
1	Gravity is like an elephant, because it can crush objects down.	Valid	Invalid
2	Gravity is like a scale, because it can rise or fall.	Valid	Invalid

During the follow-up interview, the teacher and researcher deliberated on the reasons behind their differing coding. The teacher pointed out that for responses 1 and 2, she perceived the students' descriptions as lacking specificity. In response, the researcher clarified that although the students' answers might not have been particularly specific or accurate, they still adhered to the MIPVU principle. This principle is a guideline used in this research to determine the acceptability of metaphors.

Part 2: Distinguishing between Universal and Culture-specific Metaphors

The table provided below illustrates the only discrepancy in coding for Part 2. The teacher's and the researcher's coding were very largely in agreement, with only one different coding result.

Table 3 5 Differences in Coding Results of Part 2

	Answer with Different Coding Results	Researcher	Science Teacher
1	Gravity is like the universe, because it has no end.	Culture-Specific	Universal

After the interview and discussion between the researcher and the teachers, a consensus was reached on the classification of a particular metaphor. Ultimately, this metaphor was categorised as culture-specific.

Part 3: Classifying students' conceptual understanding

In this segment, the researcher and teacher achieved the same in their coding results. The number of consensus and disagreement was determined, and reliability was calculated by the formula of (Miles and Huberman, 1994). Reliability = Consensus / (Consensus + Disagreement)* 100 The average reliability between the science teacher and researcher was determined as 94%. In qualitative research, it states that if the consistency between evaluations of expert and researcher is 90% and above, it provides reliability. The internal reliability check reinforces that the coding criteria employed are systematic and rigorous, thereby underscoring the reliability of the qualitative coding outcomes in this study.

3.5 Ethical Issues in the Study

Christians (2011) outlined several fundamental principles for addressing ethical issues in research, including informed consent and confidentiality. In the present study, an ethical framework was established to address three specific ethical concerns.

First, Informed consent refers to the process of providing individuals with sufficient information to make an informed decision about their participation in a study. This includes informing them of the research purpose, procedures, potential risks, and alternatives (Liamputtong, 2009). In this study, the Informed Consent Forms are presented in Appendix 1. Participants were allowed to withdraw from the study at any time. They were also encouraged to ask questions about any aspect of the study. No force, threat, or coercion was used to influence their decision to participate. Participants were fully aware of the study's nature and purpose, as well as the type of information being sought from them.

The second ethical issue concerns confidentiality, which means that individuals have the right to keep secrets and decide who is privy to them (Israel and Hay, 2006). This requires researchers to protect the privacy of participants. In the present study, it was ensured that participants' identities would not be disclosed to anyone not associated with the project. No information would be reported in a manner that could be linked to them.

Moreover, participants in this research were underage students, meanwhile, the content of interviews was associated with science concepts and language, which might be difficult for children to understand. Data analysis in this case is inevitably adult interpretations of children’s thinking. Therefore, it is essential to seek feedback from participants on the validity of data analysis. The anonymized research findings were presented to teachers in the sample school, as they have a more in-depth understanding of the participants. The summary reports of research findings and a thank you letter will be sent to the school providing access, as well as associated students, parents, and teachers.

This study underwent an ethical approval process at the University of Birmingham before fieldwork commenced and any data were collected. The ethical approval number is EN_21-1745. Additionally, with the assistance of the headteacher and teachers at the sample school, the research plan also met the research ethics standards in China.

4 FINDINGS

This chapter presents the findings of the investigation into participants’ use of metaphors for understanding scientific concepts, including questionnaire analysis findings and interview analysis findings.

The analysis is structured into four main sections. Section 4.1 examines the results from a questionnaire on metaphor identification, revealing how to categorise participants’ responses into metaphorical and non-metaphorical expressions. Section 4.2 delves into the types of metaphors used, distinguishing between universal and culture-specific metaphors. Section 4.3 explores participants’ conceptual understanding of scientific concepts through their metaphorical representations, categorised into intrinsic properties, extrinsic properties, and misconceptions. Finally, Section 4.4 integrates the analyses of metaphor types and conceptual understanding, providing a nuanced view of how these aspects interrelate. Additionally, interviews with participants shed light on the processes behind their metaphor generation, and the findings are presented in Section 4.5.

4.1 Questionnaire Analysis Findings: Metaphor Identification

In this study, a total of 2159 responses were collected from student participants. On average, each student provided 5.96 responses, meeting the requirement of a minimum of six responses in the questionnaire. Through the MIPVU approach mentioned in Section 3.4.1, all student responses were categorised into two groups: Metaphor and Invalid Response. Relevant results are shown in Table 4.1.

Table 4.1 Overall Analysis Results of Metaphor Validation

Response Type	**Number**	**%**
Metaphor	1623	75.2
Invalid Response	536	24.8
Total	2159	100

According to Table 4.1, 1623 responses were identified as Metaphor, accounting for 75.2% of the overall sample. Conversely, 536 metaphors were categorised as Invalid Response, representing 24.8% of the total. It is suggested that, of the questionnaire responses gathered, over two-thirds were categorised as Metaphor, and nearly a quarter of all responses were found to be invalid. The Metaphor group continued to be analysed in the following section, and the Invalid Responses group was removed from the analysis process.

Table 4.2 presents data on the Number and Percentage of Metaphor and Invalid Response collected over three academic years: Grade 3, Grade 4, and Grade 5. The total counts and corresponding percentages for each category are displayed for each Grade.

Table 4.2 Metaphor Validation Results Across Grade Groups

Response Type	**Grade 3**		**Grade 4**		**Grade 5**	
	Number	**%**	**Number**	**%**	**Number**	**%**
Metaphor	572	79.6	678	72.0	373	74.8
Invalid Response	147	20.4	263	28.0	126	25.2
Total	719	100.0	941	100.0	499	100.0

The data in Table 4.2 shows a slight variation in the distribution of Metaphor and Invalid Response across the three academic years. However, in each Grade, Metaphor constituted a significant majority, with their percentages ranging between 70-80%. It is important to note that the number of metaphors generated by Grade 5 is lower than that of Grades 3 and 4, attributable to fewer participants in Grade 5. However, the focus of our discussion is on percentages rather than absolute numbers, thus this disparity will not affect subsequent analyses.

The next table, labelled 4.3, categorises the analysis of responses by research concepts, showing the distribution of Metaphor and Invalid Response types along with their respective frequencies and percentages, followed by the total count of responses for each concept.

Table 4.3 Metaphor Validation Results Across Research Concepts

Concept	**Metaphor**		**Invalid Response**		**Total**
	Number	**%**	**Number**	**%**	
Magnet	359	84.7	65	15.3	424
Concave Lens	63	33.2	127	66.8	190
Vapour	224	70.0	96	30.0	320
Mercury	224	82.4	48	17.6	272
Circuit	187	81.0	44	19.0	231
Gravity	173	79.4	45	20.6	218
Buoyancy	266	91.4	25	8.6	291
Energy	127	59.6	86	40.4	213

Overall, each concept shows a variation in the distribution of Metaphor and Invalid Response. The percentage of Metaphor ranged widely from as high as 91.4% for Buoyancy to as low as 33.2% for Concave Lens. For the majority of the concepts listed—Magnet, Vapour, Mercury, Circuit, Gravity, and Buoyancy—the proportion of responses classified as Metaphor exceeds 70%. However, there are notable exceptions to this trend. The concepts of Concave Lens and Energy show significantly lower Metaphor percentages, at 33.2% and 59.6% respectively.

4.2 Questionnaire Analysis Findings: Metaphor Type Analysis

In the theoretical framework developed for this research, all metaphors identified in the last coding step were categorised into two types: Universal Metaphor and Culture-specific Metaphor. This classification system was proposed in Section 3.4.1. A characteristic feature of a Universal Metaphor is its source domain, which originates from common sensorimotor experiences and therefore has the potential to be universally understood. In contrast, Culture-specific Metaphor arise from experiences without direct physical engagement.

This section delineates the outcomes of the second step of coding. Section 4.2.1 details the distribution of two metaphor types identified during the second coding phase. Sections 4.2.2 and 4.2.3 offer illustrative examples to elucidate these metaphor categories. Finally, Sections 4.2.4 and 4.2.5 examine the variations in distribution across different academic years and within distinct research concepts.

4.2.1 Distribution of Metaphor Type across All Valid Metaphors

From the 1623 valid Metaphor identified in the last step of coding, participants employed 348 distinct source domains to create valid metaphors, which have been categorised into five groups: Physical Entity, Human Body, Abstract Concept, Non-Physical Entity, and Language Character. These five categories emerged from the coding of students' source domain types. Regarding the Universal Metaphor, the first two groups—Physical Entity and Human Body—are associated with embodied experiences that are common to participants and humanity at large, and are therefore categorised as Universal Metaphor, according to the coding criteria presented in Section 3.4.2. The last three groups are not directly produced by sensorimotor experiences and are thus categorised as Culture-specific Metaphor.

The statistical results of this coding are displayed in the table below.

Table 4.4 Overall Analysis Results of Metaphor Type Categorisation

Metaphor Type	**Number**	**Percent**
Universal Metaphor	1482	91.3
Culture-Specific Metaphor	141	8.7
Total	1623	100

The table above presents the results of the second coding, categorisation of metaphors into two distinct types: Universal Metaphor and Culture-Specific Metaphor. Universal Metaphors are significantly more prevalent, with a total count of 1,482, accounting for 91.3% of all valid metaphors. In contrast, Culture-Specific Metaphors are less common, with 141 instances, making up 8.7% of the total. It shows that compared to Culture-Specific Metaphor, Universal Metaphor has a significantly larger proportion.

4.2.2 Examples of Universal Metaphor

As mentioned before, the source domain of Universal Metaphor in this research were two kinds: Physical Entities and Human Body. This section presents examples illustrating how participants employed them to create a Universal Metaphor. The number of these two kinds of source domains is 1370 and 112, and their proportions in the universal metaphor are 92.5% and 7.5%, respectively. The table below shows the distribution of these two types across three grades.

Table 4 5 Distribution of Physical Entities and Human Body across Grade Groups

Grade	**Physical Entities**		**Human Body**		**Total**
	Number	**%**	**Number**	**%**	
Grade 3	484	93.4	50	6.6	534
Grade 4	591	91.7	31	8.3	622
Grade 5	295	87.4	31	12.6	326

The table data above show that as grade levels increase, the number and percentage of Physical Entities gradually decrease, while the percentage of the Human Body significantly increases by participant Grade. This shift is especially notable in grade 5, where the focus on the human body significantly rises.

For Physical Entities, it includes all source domains that have a physical form in the real world, whether they are living or non-living. There are many kinds of physical entities that were utilised as source domains in this category, which contain various roles and characteristics related to physical objects, humans, and animals. Examples are listed in Table 4.6.

Table 4.6 Examples of Physical Entity as Universal Metaphor's Source Domains

	Concept	**Participant Number**	**Example**
Physical Objects	Magnet	3509	*Magnet is like the glue, because it can stick things together.*
	Concave Lens	4308	*Concave Lens is like a spoon, because its shape is concave.*
	Vapour	5326	*Vapour is like balloon, because it can float.*
	Mercury	3211	*Mercury is like water, because it can flow.*
	Circuit	4618	*Circuit is like a road, because they have the same shape.*
	Energy	5117	*Energy is like a food, because it can make us have power.*
	Gravity	4409	*Gravity is like stone, because it is very heavy.*
	Buoyancy	5529	*Buoyancy is like boat, because it can be floating.*
Human	Magnet	3309	*Magnet is like twins, because they always connect to each other.*
	Concave Lens	4721	*Concave Lens is like an assistant, because it can help see clearly.*
	Mercury	3502	*Mercury is like the child, because they can also go up and down.*
	Energy	4213	*Energy is like people, because it can move objects.*
	Gravity	5503	*Gravity is like a fat man, because it can move objects.*
	Buoyancy	5724	*Buoyancy is like people, because it can make things float.*
Animal	Magnet	3714	*Magnet is like a chameleon, because it has lots of colours.*
	Vapour	4401	*Vapour is like a bird, because it flies in the sky.*
	Mercury	5723	*Mercury is like animal, because it can move.*
	Circuit	3522	*Circuit is like the snake, because they have the same shape.*
	Energy	4704	*Energy is like the bear, because it is very heavy.*
	Gravity	5518	*Gravity is like the elephant, because it is very heavy.*
	Buoyancy	3816	*Buoyancy is like a duck, because it can float on the water surface.*

The table above lists examples of using physical entities as source domains provided by participants in this study. These metaphors were produced based on physical entities including physical objects, human, and animals. Under physical objects, participants drew parallels between a concept and a tangible object, such as likening a Magnet to glue due to its adhesive nature, or a Concave Lens to a spoon because of its concave shape. Other examples include Vapour compared to a balloon for its ability to float, Mercury to water for its fluidity, a Circuit to a road due to similar shape, Energy to food as a source of power, Gravity to a stone for its heaviness, and Buoyancy to a boat for its floating ability.

In the human category, metaphors compared concepts to human characteristics or roles. For instance, a Magnet was compared to twins for their connection, a Concave Lens to an assistant for its aid in seeing clearly, Mercury to a child for its ability to go up and down, Energy and Gravity to people for their ability to move objects, and Buoyancy to people for making things float.

The animal category includes metaphors where concepts are likened to animals: a Magnet is compared to a chameleon for its colours, Vapour to a bird for flying, Mercury simply to an animal for its movement, a Circuit to a snake for its shape, Energy and Gravity to heavy animals like a bear and an elephant for their weight, and Buoyancy to a duck for floating on water.

The coding results reveal that the most prevalent source domain in this category is physical objects, with 238 types employed by students. This was the sole category demonstrating overlapping source domains across all participant groups and researched concepts, with humans and animals featuring in 19 and 11 varieties, respectively.

Except for Physical Entity, students also utilised the human body parts for metaphor generation. This category includes source domains related to the structure and function of the human body. As shown in Table 4.7, these metaphors were also evident across all seven scientific concepts, with the exception of Mercury. Many of these instances were derived from the interaction between body parts and the environment, and include the hand, foot, nose, eyes, mouth, fist, palm, and muscle.

Table 4.7 Examples of Human Body as Universal Metaphor's Source Domains

Concept	**Participant Number**	**Examples**
Magnet	3304	*Magnet is like heart, because it can connect with others.*
Concave Lens	3526	*Concave Lens is like our eyes because it can make us see things clearly.*
Vapour	4321	*Vapour is like our hands, because it can be expanded.*
Circuit	4513	*Circuit is like our brain, because it can conduct electricity.*
Energy	4119	*Energy is like our blood, because it is inside our body.*
Gravity	5703	*Gravity is like our hands, because they can press us to the ground.*
Buoyancy	3217	*Buoyancy is like human palm, because it can make things float.*

Table 4.7 provides examples of the way participants employed the human body to metaphorically elucidate various scientific concepts. For example, the intrinsic attraction of a Magnet is likened to the heart. Similarly, the clarifying function of a Concave Lens finds its metaphorical counterpart in our eyes, an organ intrinsic to human vision. Further, the Circuit is compared to our brain and Energy, the life force of many systems, is paralleled with our blood. Within this category, the most frequently referenced source domain was the *hand*, which was widely used among five of the scientific concepts (as shown in Table 4.8).

Table 4.8 Examples of Hand as Universal Metaphor's Source Domains

Concept	**Participant Number**	**Examples**
Magnet	3315	*Magnet is like our hands, because they can stick to other things.*
Vapour	4502	*Vapour is like our hands, because it can be expanded.*
Energy	5325	*Energy is like our hands, because they can move objects.*

Gravity	3312	*Gravity is like our hands, because they can press us to the ground.*
Buoyancy	4709	*Buoyancy is like our hands, because they can make other things float.*

Students often used the hand to express the movement related to these concepts, including its internal movement and its effects on other objects. This reflected one of primary functions of the hand in everyday life, which is to move objects. A similar trend could be seen in the description of Concave Lenses by Grade 4 students: *Concave Lens is like our eyes because they can make us see things clearly*. These expressions indicate that the choice of source domain was linked to the way in which a specific body part is utilised in producing embodied experiences during everyday life.

In a nutshell, universal metaphors are constructed from two principal source domains: Physical Entities and the Human Body. Physical Entities encompass living and non-living forms, utilised to illustrate scientific concepts metaphorically through their roles, characteristics, and behaviours. The Human Body domain includes metaphors derived from body parts, such as hand.

4.2.3 Examples of Culture-Specific Metaphor

As mentioned in the last section, the source domain of culture-specific metaphors consists of three categories, Abstract Concept, Non-Physical Entity, and Language Character. The number of these three kinds of source domains is 92, 41 and 8, and their proportions in the universal metaphor are 65.2%, 29.1%, and 5.7%, respectively. The table below shows the distribution of these three types across three grades.

Table 4.9 Distribution of Abstract Concept, Non-Physical Entity, and Language Character across Grade Groups

Grade	**Abstract Concept**		**Non-Physical Entity**		**Language Character**		**Total**
	Number	**%**	**Number**	**%**	**Number**	**%**	
Grade 3	24	63.2	11	29.0	3	7.8	38
Grade 4	42	75.0	10	17.9	4	7.1	56
Grade 5	26	55.3	20	42.6	1	2.1	47

Based on the data above, it is evident that the numbers and percentages in the categories of Abstract Concepts and Language Characters change significantly across Grades 3, 4, and 5. In contrast, in the Language Characters category, Grades 3 and 4 have 3 (7.8%) and 4 (7.1%), respectively, while Grade 5 decreases to 1 (2.1%).

For Abstract Concept, by using this category, students employed abstract concepts to metaphorically express their understanding. The source domains from this category cross science, philosophy, culture, and daily life. It refers to ideas that don't have a physical form but occupy a central position in human knowledge, experience, and culture. These concepts could be scientific theories, like *Gravity* and *Energy*, or everyday concepts like *winter*.

Table 4.10 Examples of Abstract Concepts as Culture Specific Metaphor's Source Domains

Concept	**Participant Number**	**Example**
Magnet	3618	*Magnet is like Gravity, because it can stick things up.*
Vapour	3427	*Vapour is like carbon dioxide, because it can flow in the sky.*
Mercury	4303	*Mercury is like formaldehyde, because it is toxic.*
Circuit	4711	*Circuit is like nervous system, because it can all pass something.*

Energy	5418	*Energy is like fat, because it can make machines work.*
Gravity	5203	*Gravity is like the universe, because it is endless.*
Buoyancy	3421	*Buoyancy is like hydrogen, because it can make things flow up.*

In the examples listed in Table 4.10, by drawing upon Abstract Concept source domains, they were better able to comprehend and relate to unfamiliar or intricate ideas. For example, when a student likened a Magnet to Gravity, they drew attention to the inherent property of attraction that both phenomena possessed. Similarly, the comparison of Vapour to carbon dioxide underscored their gaseous nature and their movement in the atmosphere. Another insightful example was the comparison of Mercury to formaldehyde. This metaphor reflected a student's awareness of the potential hazards of certain chemicals, emphasizing the need for safety and caution. The parallel between a Circuit and the nervous system showcased the student's understanding of transmission and relay mechanisms in both electrical and biological systems. By likening Energy to fat, a student effectively tapped into the concept that fat served as a reservoir of Energy in biological systems, analogous to how Energy powered machines. The metaphor comparing Gravity to the universe touched upon the omnipresence and vastness of gravitational forces that existed. Lastly, the association between Buoyancy and hydrogen brought forth the idea of ascent or rising, emphasizing the upward movement inherent in both Buoyancy in liquids and hydrogen in the presence of denser gases. These metaphorical expressions highlighted the students’ ability to interweave diverse scientific domains, enriching their conceptual grasp and offering a unique perspective on their learning journey.

For Non-Physical Entity, this category refers to those entities that exist within human thoughts, perceptions, and beliefs but don’t physically exist in reality. This theme encompassed entities that exist in fiction and are not physically present in reality, such as magic, monsters, pixies, etc., and students used the specific properties of these entities to generate metaphorical expressions. Such an approach showcased their innovative thinking and their ability to merge the abstract with the concrete.

Table 4.11 Examples of Non-Physical Entities as Culture Specific Metaphor’s Source Domains

Concept	**Participant Number**	**Example**
Magnet	5224	*Magnet is like magic, because it can stick things up.*
Concave Lens	3309	*Concave Lens is like thousand-mile eye, because it can help us see clearly.*
Vapour	4201	*Concave Lens is like elves, because it is everywhere.*
Mercury	3519	*Mercury is like monster, because it can bring us danger.*
Energy	5216	*Energy is like Hulk, because it can bring us the power.*
Gravity	4814	*Gravity is like monster, because it can bring us danger.*
Buoyancy	3629	*Buoyancy is like magic, because it can flow things up.*

For instance, in Table 4.11, the likening of a Magnet to magic highlighted the mysterious and seemingly inexplicable nature of magnetic attraction. Similarly, the comparison of a Concave Lens to a ‘thousand-mile eye’ tapped into the idea of distant or enhanced vision, emphasizing the lens's capability to improve clarity in viewing. The metaphor associating Vapour with elves was particularly evocative, suggesting the omnipresence and elusive nature of both. Mercury, known for its potential hazards, was aptly compared to a monster, illustrating the element's dangerous properties. Interestingly, Mercury was also likened to Hulk, a fictional character known for his immense power, possibly denoting the dual nature of Mercury as both potent and perilous. Gravity, a force that binds us to the earth and can have catastrophic consequences if not respected, was also metaphorically related to a monster. Lastly, Buoyancy's capacity to make objects float was paralleled with magic, emphasizing its seemingly miraculous ability to counteract the force of Gravity. Through these metaphorical expressions, students effectively bridged the gap between the tangible world of science and the imaginative realm of fiction, demonstrating their creative approach to understanding complex concepts.

For Language Character, this category relates to the foundational elements of language, span different languages, from basic letters and symbols to intricate words and phrases. The source domains within this category in this research includes students using their native language Chinese and English they have learned.

Table 4.12 Examples of Language Characters as Culture Specific Metaphor' Source Domains

Concept	**Participant Number**	**Examples**
Magnet	3328	*Magnet is like letter N, because they have the same shape.*
Magnet	4209	*Magnet is like letter O, because they have the same shape.*
Magnet	5518	*Magnet is like letter U, because they have the same shape.*
Magnet	3119	*Magnet is like Chinese character 一(one), because they have same shape.*
Concave Lens	5124	*Concave Lens is like character 凹 (concave), because they have same shape.*

In illustrating the physical resemblance between different entities, students employed parallels between their shapes. For instance, a Magnet was likened to the *letters N, O,* and *U* because of their similar forms. Similarly, its shape is reminiscent of the Chinese character for 'one', 一. On another note, the shape of a Concave Lens was compared to the Chinese character for ‘concave’, 凹, emphasising their visual similarity.

In summary, this section details the source domain of culture-specific metaphors which include Abstract Concept, Non-Physical Entity, and Language Character. These metaphors enrich participants’ expression by connecting scientific ideas with various of source domains.

4.2.4 Distribution of Metaphor Type Across Three Grade Groups

As mentioned in Section 3.4.1, the Chi-Square Test, a common statistical method for detecting significant associations between two categorical variables, was utilised to explore the potential correlation between Metaphor Type and student Grade groups. In statistical analysis, a p-value below the predetermined significance level, typically set at 0.05, indicates that the results are statistically significant (Muijs, 2010). This suggests there is adequate evidence to reject the null hypothesis of no relationship between the variables under investigation. After collecting and organising the data, the variables were input into IBM SPSS Statistics (Version 29.0.1.1, 2023) for analysis. The relevant results are listed in Table 4.13.

Table 4.13 Chi-Square Test Results of Metaphor Type Across Three Grade Groups

	Value	**df**	**P Value**
Pearson Chi-Square	10.369	2	0.006

Results show that the Asymptotic Significance, or the p-value, came out to be 0.006, which is well below the standard significance level of 0.05, there is strong statistical evidence to suggest a significant association between the types of metaphors used and the grade levels of students.

However, it is important to note that while the Chi-Square Test reveals a statistical association between the variables, it does not provide details on the nature of the association (such as whether it is positive or negative) nor information about causality. Therefore, further examination of the specific metaphor types used in each grade level will follow to gain deeper insights. The distribution of Metaphor Type across three Grade groups is presented in Table 4.14.

Table 4.14 Distribution of Metaphors Type across Grade Groups

Grade	**Universal Metaphor**		**Culture-Specific Metaphor**		**Total**
	Number	**%**	**Number**	**%**	
Grade 3	534	93.4	38	6.6	572
Grade 4	622	91.7	56	8.3	678
Grade 5	326	87.4	47	12.6	224

Table 4.14 shows a consistent predominance of Universal Metaphor across all Grades, and there is a notable increase in the percentage of Culture-Specific Metaphor from Grade 3 (6.6%) to Grade 5 (12.6%).

4.2.5 Distribution of Metaphor Type Across Research Concept

To investigate the relationship between metaphor type and research concept, the same statistical method, the Chi-Square Test, was applied. The results of this analysis are displayed in the subsequent table.

Table 4.15 Chi-Square Test Results of Metaphor Type and Research Concept

Pearson Chi-Square	**Value**	**df**	**P Value**

	51.776	7	<0.001

The results of the Chi-Square Test shows in Table 4.15 applied to explore the relationship between metaphor type and research concept reveal that the Asymptotic Significance, or the p-value, is less than 0.001. This value is significantly below the standard significance level of 0.05, providing strong statistical evidence to suggest a significant association between the types of metaphors used and the research concepts. The distribution of Metaphor Type across eight research concepts is presented in Table 4.16.

Table 4.16 Distribution of Metaphors Type across Research Concept

Concept	**Universal Metaphor**		**Culture-Specific Metaphor**		**Total**
	Number	**%**	**Number**	**%**	
Magnet	328	91.4	31	8.6	359
Concave Lens	50	79.4	13	20.6	63
Vapour	211	94.2	13	5.8	224
Mercury	211	94.2	13	5.8	224
Circuit	180	96.3	7	3.7	187
Gravity	150	86.7	23	13.3	173
Buoyancy	251	94.4	15	5.6	266
Energy	101	79.5	26	20.5	127

From the table, it is evident that the majority of metaphors generated by the students for these scientific concepts are categorised as Universal Metaphor, with the number percentages significantly higher than those of Culture-Specific Metaphor.

This table also shows that the concept of Concave Lens has the highest proportion of Culture-Specific Metaphor at 20.6%, followed closely by Energy with 20.5%. These figures notably exceed the average rate of 8.7% by more than double. Within the category of Energy, 26 metaphors were categorised as culture-specific, 21 of which are ascribed to the diverse forces employed in their source domains, including Gravity, friction, and kinetic force. Regarding Concave Lens, 13 metaphors were categorised as culture-specific; seven are attributable to the source domain of *thousand-mile-eyes*, and the remaining six pertain to *clown*.

On the other hand, concepts including Circuit, Vapour, Mercury, and Buoyancy exhibit a lower incidence of Culture-Specific Metaphor, all below 6%. The proportion of Culture-Specific Metaphors for Magnetism and Gravity is in the mid-range for the eight selected concepts.

4.3 Questionnaire Analysis Findings: Conceptual Understanding Type

In the theoretical framework developed for this research, all metaphors identified in the last coding step are categorised into three types based on the understandings reflected: Intrinsic Property, Extrinsic Property, Misconception. The classification system outlined in Section 3.4.1 differentiates between Intrinsic and Extrinsic Property. An Intrinsic Property is defined by its inherent dependence on the concept itself. Conversely, an Extrinsic Property is contingent upon external factors. Misconception refers to erroneous interpretations or understandings of scientific concepts.

This chapter delineates the outcomes of the third step coding. Section 4.3.1 details the distribution of three conceptual understanding types identified during the third coding phase. Sections 4.3.2, Section 4.3.3 and 4.3.4 offer illustrative examples to elucidate these conceptual understanding categories comprehensively. Finally, Sections 4.3.5 and 4.3.6 examine the variations in distribution across different academic years of participants and within distinct research concepts.

4.3.1 Distribution of Conceptual Metaphor Type across All Valid Metaphors

Through qualitative analysis of all valid metaphors, all students' understandings of eight research concepts were categorised into three categories: Intrinsic Properties, Extrinsic Properties, and Misconceptions. The results are listed below.

Table 4.17 Overall Analysis Results of Conceptual Understanding Type

Conceptual Understanding Type	Number	%
Intrinsic Properties	997	61.4
Extrinsic Properties	339	20.9
Misconceptions	287	17.7
Total	1623	100

Table 4.17 displays the distribution of frequencies and percentages of different types of conceptual understanding among participants. It shows that Intrinsic Properties are the most frequent at 61.4%, followed by Extrinsic Properties at 20.9%, and Misconceptions are the least frequent at 17.7%.

The data above illustrates the statistical distribution of the Conceptual Understanding Type. The subsequent section will provide specific instances of the three categories of conceptual understanding, along with their distribution among the participant’s grade group and research concepts.

4.3.2 Examples of Intrinsic Property

In the theoretical framework developed for this research, the Intrinsic Property refers to the inherent attributes of concepts that define their core nature without external influence. This category includes the characteristics that remain unchanged across varying environments or conditions. The following table presents examples of metaphors that reflect understandings of Intrinsic Property.

Table 4.18 Examples of Metaphors Reflect Intrinsic Properties Understanding of Scientific Concepts

Concept	**Participant Number**	**Examples**
Magnet	5722	Magnet is like glue, because it can stick something.
	3719	Magnet is like enemy, because they sometimes cannot be together.
Concave Lens	5704	Concave Lens is like sun, because it can reflect the light.
	5507	Concave Lens is like a mountain, because they all have concave shape.
	4702	Concave Lens is like water, because they all have transparent.
Vapour	3528	Vapour is like air, because it cannot be seen.
	3711	Vapour is like balloon, because it can move.
	4725	Vapour is like invisible people, because we cannot hold it.
Mercury	5317	Mercury is like poison, because it is toxic.
	5322	Mercury is like bear, because they can all change their shape.
Circuit	5727	Circuit is like road, because it can pass electricity.
	3506	Circuit is like rope, because they can be connected to each other.
Gravity	5325	Gravity is like energy, because it can press objects.
	4301	Gravity is like magnet, because it can pull us to the ground.
Buoyancy	4815	Buoyancy is like hand, because it can make things flow.

	3707	Buoyancy is like air, because it is invisible.
Energy	4501	Energy is like blood, because it can exist in our body.
	4817	Energy is like battery, because its amounts can go up and down.
	5809	Energy is like air, because it is invisible.

Table 4.18 provides examples of metaphors that reflected students’ understanding of Intrinsic Property of various scientific concepts. These metaphors reflected in the table demonstrate an understanding of intrinsic properties that are fundamental and universal to the research concepts, not limited to specific circumstances. For instance, the attraction and repulsion of a Magnet are inherent physical properties that remain effective regardless of the environment. Similarly, the invisibility of Vapour, the fluidity of Mercury, the conductivity of a Circuit, and the gravitational pull of Gravity are inherent characteristics of these concepts, applicable in any situation. These attributes are an integral part of the concepts themselves, consistent and unvarying regardless of external conditions.

All intrinsic properties can be categorised into two types.

The first type concerns properties that involve only the concept itself and describe its stable state. For example, the metaphor sun was coined for the concept of the Concave Lens to illustrate its ability to reflect light, highlighting the lens's inherent optical property. The metaphor mountain denotes their shared concave shape, while water signifies their transparency. These properties are pertinent exclusively to the Concave Lens. Other relevant properties include the invisibility of Vapour, Energy, Buoyancy

The second type pertains to properties related to the impact of concepts on other objects. For instance, the concept Magnet is described as glue due to its ability to adhere to objects, and enemy to denote the repulsion between like poles, reflecting both the Magnet's characteristic of attraction and its effect on other entities. Similarly, Gravity is characterised as Energy because of its pressing effect on objects, revealing Gravity's essence as a fundamental force and its impact on other entities. Buoyancy is compared to hand for its capacity to make objects float, which exemplifies the lifting property of Buoyancy.

In this section, intrinsic properties of scientific concepts were presented and categorised into two distinct types: one intrinsic to the concept itself and another related to the concept’s effect on other entities. Metaphors derived from both inherent qualities and interactive characteristics effectively elucidate properties of these concepts that do not depend on the environment.

4.3.3 Examples of Extrinsic Property

According to the coding criteria proposed in Section 3.4.2, extrinsic properties was proposed as understanding that describes the property which dependent on external conditions. Relevant examples are listed in Table 4.19.

The metaphors that students provided in Table 4.19 reflect their understanding of the scientific concepts’ extrinsic properties, which are characteristics that manifest in specific situations. There is no response for the concept of Gravity and Buoyancy. These extrinsic properties are mainly defined for three reasons.

Table 4.19 Examples of Metaphors that Reflect Extrinsic Properties of Understanding of Scientific Concepts

Concept	**Participant Number**	**Examples**
Magnet	5307	Magnet is like stone, because it is hard.
	4822	Magnet is like a ball, because it can move.
	4708	Magnet is like letter U, because they have the same shape.
	3320	Magnet is like a black cookie, because they have same colour.
	5707	Magnet is like stone, because it is really heavy.
Concave Lens	3710	Concave Lens is like a clown, because it can make people laugh.
	4504	Concave Lens is like a toy, because we like to play it.
Vapour	3823	Vapour is like a pot, because it can generate water.
	5707	Vapour is like freezer, because it can cool things down.
	4815	Vapour is like elf, because it is everywhere.
	3825	Vapour is like air, because it is really light.
	5705	Vapour is like bomb, because it can cause damage.
Mercury	3318	Mercury is like water, because it can also move.
	5303	Mercury is like gem, because they are all really beautiful.
Circuit	3515	Circuit is like a pen, because they have same size.
	4809	Circuit is like a maze, because it is complex.
	3726	Circuit is like road, because it is very long.
	5705	Circuit is like blood, because it can make machine work.
	4703	Circuit is like weapon, because it is dangerous.
Gravity		
Buoyancy		
Energy	5706	Energy is like strength, because it can make things move.

First, it is related to students' personal experiences, like the description that Magnet is heavy, and Circuit is complex. For example, the Magnet is described as "stone" because it is hard, an external physical property that can only be perceived through touch or interaction, and different various kinds of Magnets. Similarly, the Circuit being likened to a "maze" suggests its complexity in design and layout, and this expression is also subject and different among individuals.

The second reason is that the understanding students describe is related to the concept, but also other factors. For example, the Magnet can move but also needs other assistance, and the Circuit is dangerous but only in certain circumstances. The Vapour compared to "pot" is based on the generation of steam when water is heated, a transformation process that occurs under certain conditions.

Third, the character students presented is only for specific one of the concepts, but not for all. For example, the colour black is only for some Magnets, but not the property that same for all Magnets.

Overall, the properties displayed in these metaphors are external and dependent on specific circumstances and may not be inherent to the concepts themselves but are characteristics that emerge in certain conditions or environments.

4.3.4 Examples of Misconception

Misconception is defined as an understanding that is in contrast with its explanation in the scientific context of this research. Examples are listed in Table 4.20.

The metaphors provided in the table above reflect misconceptions students have about certain scientific concepts. These conceptual understandings were categorised as misconceptions primarily for two reasons.

Table 4.20 Examples of Metaphors Reflect Misconceptions of Scientific Concepts

Concept	**Participant Number**	**Examples**
Magnet		
Concave Lens	4809	Concave Lens is like a lighter, because it can set fire.
Vapour	3505	Vapour is like white paint, because it is white.
Mercury	3320	Mercury is like air, because it is transparent.
Circuit	5527	Circuit is like sweater, because it can generate electricity.
	3713	Circuit is like star, because it can shine.
	5729	Circuit is like water, because it can move.
Gravity	4326	Gravity is like Buoyancy, because it can make us fly.
	3309	Gravity is like stone, because it is heavy.
	5703	Gravity is like water, because it can fall down.
Buoyancy	4518	Buoyancy is like balloon, because it is light.
	3702	Buoyancy is like plain, because it can fly to the sky.
Energy	3813	Energy is like fire, because it is really hot.
	5526	Energy is like iron, because it is really heavy.

The first reason is their divergence from the scientific understanding of these concepts. In the table, a Concave Lens is described as “lighter” because it can ignite fire, which is a misconception. The actual function of a Concave Lens is to diverge light, not to produce flames therefore cannot be used to generate fire. Vapour is compared to “white paint” because it appears white. This is inaccurate since Vapour itself is colourless; what is often perceived as white Vapour is actually tiny droplets of water suspended in the air. Mercury is likened to “air” because it is transparent. This is a misunderstanding because, although Mercury is a liquid that can flow, it is a metallic element with a distinctive silvery appearance, unlike air, which is invisible.

Circuits are metaphorically described in various ways: “sweater” because it can generate electricity, which is clearly incorrect as Circuit cannot produce electrical power but conduct it. These are all wrong understandings of scientific concepts.

The second reason is that for abstract concepts, where students attributed properties that cannot be associated with abstract concepts, such as being heavy or hot. For example, Energy is related to “fire” because it is very hot and “iron” because it is very heavy. These metaphors are inappropriate because in this metaphor fire is a form of Energy characterised by heat. However, Energy itself does not have temperature and is not the same as a tangible entity with measurable weight in everyday contexts. Energy can also exist in various forms, such as thermal, kinetic, or electrical.

The section highlights the categorisation of students’ misconceptions through metaphors that contrast with established scientific explanations. Misconceptions are identified due to their deviation from scientific facts and the attribution of inappropriate properties to abstract concepts.

4.3.5 Distribution of Conceptual Understanding Type Across Participant Grade Group

To investigate the relationship between Conceptual Understanding Type and participants' Grade groups, the same statistical method, the Chi-Square Test, was applied. The results of this analysis are displayed in the subsequent table.

Table 4.21 Chi-Square Test Results of Conceptual Understanding Type and Three Grade Groups

	Value	**Df**	**P Value**
Pearson Chi-Square	10.125	4	0.038

The results of the Chi-Square Test shown in Table 4.21 applied to explore the relationship between metaphor type and research concept reveals that the Asymptotic Significance, or the p-value, is 0.038. This value is significantly below the standard significance level of 0.05, providing strong statistical evidence to suggest a significant association between the types of metaphors used and the research concepts. The distribution of Conceptual Understanding Type across three Grade groups is presented in Table 4.22.

Table 4.22 Distribution of Conceptual Understanding Type Across Grade Groups

Grade	**Intrinsic Property**		**Extrinsic Property**		**Misconception**	
	Number	**%**	**Number**	**%**	**Number**	**%**
Grade 3	362	63.3	123	21.5	87	15.2
Grade 4	398	58.7	136	20.1	144	21.2
Grade 5	237	63.5	80	21.4	56	15.0

Table 4.22 displays the descriptive analysis results which compare the Number and percentage of metaphor types used by students across three different school Grades:

Grade 3, Grade 4, and Grade 5. According to these results, across the Grades, Intrinsic Property metaphors maintain the majority consistently over 58%. Misconception metaphors, while the least frequent, peak in Grade 3 at over 21.5%. Extrinsic Property presents a relatively stable trend across the Grades but dip in Grade 4 to 20.1%. However, overall, the distribution of the three types of understanding across the three grade levels does not vary significantly.

4.3.6 Distribution of Conceptual Understanding Type Across Research Concept

To investigate the relationship between Conceptual Understanding Type and research concepts, the same statistical method, the Chi-Square Test, was applied. The results of this analysis are displayed in the subsequent table.

Table 4.23 Chi-Square Test Results Conceptual Understanding Type and Research Concept

	Value	**Df**	**P Value**
Pearson Chi-Square	711.941	14	<0.001

The results of the Chi-Square Test presented in Table 4.23 explore the relationship between metaphor type and research concept reveal that the Asymptotic Significance, or the p-value, is less than 0.001. This value is significantly below the standard significance level of 0.05, providing strong statistical evidence to suggest a significant association between the types of metaphors used and the research concepts. The distribution of Conceptual Understanding Type across three Grade groups is presented in Table 4.24.

Table 4.24 Distribution of Conceptual Understanding Type Across Research Concepts

Concept	Intrinsic Property		Extrinsic Property		Misconception	
	Number	%	Number	%	Number	%
Magnet	331	92.2	28	7.8	0	0.0
Concave Lens	42	66.7	10	15.8	11	17.5
Vapour	170	75.9	34	15.2	20	8.9
Mercury	128	57.1	87	38.8	9	4.0
Circuit	62	33.2	57	30.5	68	36.4
Gravity	88	50.9	0	0.0	85	49.1
Buoyancy	132	49.6	0	0.0	134	50.4
Energy	44	34.6	70	55.1	13	10.2

Table 4.24 presents a descriptive analysis of the types of conceptual understanding reflected in the metaphors used for different scientific concepts. The table demonstrates a varied level of understanding across different concepts, with some concepts like the Magnet showing a clear and consistent grasp of intrinsic nature, while others like Circuit, Gravity, and Buoyancy exhibit significant levels of misconceptions. Variations in the types of understanding are evident across different concepts, yet some notable patterns emerge.

Firstly, the four concepts of Magnet, Concave Lens, Vapour, and Mercury are tangible entities that physically exist in everyday life. Regarding these four concepts, except for Mercury, their intrinsic properties substantially exceed the average by 61.4%. Magnets, in particular, show an intrinsic property percentage more than 30% above the average. Moreover, their extrinsic property percentages, as well as those for misconceptions, are all lower than the average.

In the case of Mercury, the percentage of misconceptions is considerably less than the average of 17.7%, yet its extrinsic property percentage is higher than intrinsic properties. Examining the participants' responses reveals that Mercury's extrinsic properties involve 87 metaphors, with 40 describing Mercury's motion and 18 describing its form—some characterising it as a solid, others as a liquid.

As for the latter four abstract concepts—Circuit, Gravity, Buoyancy, and Energy—all have intrinsic property percentages significantly below the average. This is particularly the case for Circuits and Energy, which are merely half of the average. Meanwhile, their misconception percentages, excluding Energy, are several times higher than the average of 17.7%, specifically 36.4%, 49.1%, and 50.4%.

Furthermore, the abstract concepts' extrinsic properties are highly distinctive. The extrinsic properties of two concepts, Circuit and Energy, exceed the average, with Energy's being more than double. In contrast, the extrinsic property percentages for Gravity and Buoyancy are 0, which is unique compared to all other concepts.

Overall, intrinsic property understanding typically maintains a strong presence across various scientific concepts, yet the rates of extrinsic property understanding, and misconceptions show significant variation among the different concepts. The following analysis will delve into how these various types of understanding intertwine with the metaphor types.

4.4 Questionnaire Analysis Findings: Integrating Metaphor Types and Conceptual Understanding Type

This section focuses into the fourth analysis step, outlined in Section 3.4.2, which is the analysis of Metaphor Types and Conceptual Understanding. It investigates the potential correlation between the metaphors employed by students and their conceptual understandings as reflected in their responses.

Section 4.4.1 presents the Chi-Square Test results of this combination. Following that, Section 4.4.2 provides examples illustrating the various metaphors participants used to express different types of understanding. Sections 4.4.3 and 4.4.4 demonstrate the variation in this combination across different grades and scientific concepts, respectively.

4.4.1 Statistical Correlation between Conceptual Understanding Type and Metaphor Type

To investigate the relationship between students' use of Metaphor Type and their conceptual understanding reflected, the Chi-Square Test was applied. The results of this analysis are displayed in the subsequent table.

Table 4.25 Chi-Square Test Results of Metaphor Type and Conceptual Understanding Type

	Value	**df**	**P Value**
Pearson Chi-Square	22.045	2	<.001

The results of the Chi-Square Test shown in Table 4.25 applied to explore the relationship between metaphor type and research concept reveal that the Asymptotic Significance, or the p-value, is less than 0.001. This value is significantly below the standard significance level of 0.05, providing strong statistical evidence to suggest a significant association between the metaphor types of metaphors and reflected conceptual understanding. However, as mentioned before, it is important to note that the Chi-Square Test reveals a statistical association between the variables, it does not provide details on the nature of the association (such as whether it is positive or negative) nor information about causality. Therefore, it is necessary to further examine how specific types of metaphors are connected to conceptual understanding.

4.4.2 Distribution of Conceptual Understanding Type across Metaphor Type

By integrating Coding Step 2, Metaphor Type Analysis, with Coding Step 3, Conceptual Understanding Analysis, six types of combinations are generated, as depicted in the table below.

Table 4.26 Distribution of Conceptual Understanding Type Across Metaphor Type

Conceptual Understanding Type	**Metaphor Type**	
	Universal Metaphor Number (%)	Culture-Specific Metaphor Number (%)
Intrinsic Property	901 (90.4)	96 (9.6)
Extrinsic Property	251 (87.5)	36 (12.5)
Misconception	330 (97.3)	9 (2.7)

The table above delineates an analysis of Conceptual Understanding Types across various Metaphor Types. It demonstrates that each type of understanding within the study is articulated through two distinct metaphors. In the overall distribution of universal metaphors and culture-specific metaphors, they account for 91.3% and 8.7%, respectively. The data presented in the table indicate that for intrinsic and extrinsic properties, the proportion of culture-specific metaphors employed is higher than its average use among all metaphors in this study (8.7%). Conversely, universal metaphors are more prevalently used for misconceptions, while the proportion of culture-specific metaphors is approximately one quarter of the average.

For intrinsic properties, participants in this study utilised both universal and culture-specific metaphors to illustrate them. Of these, 901 metaphors, accounting for 90.4%, were universal, while 96 were culture-specific metaphors, making up 9.6%. Table 4.27 (Page 199) provides relevant examples.

These examples illustrate how the understanding of intrinsic properties identified in the third step of coding, as detailed in Section 4.3.1, is conveyed through both universal and culture-specific metaphors. Intrinsic properties, which are fundamental and universally applicable to the research concepts and not confined to particular contexts were metaphorically projected onto other entities, whether they emerged from embodied experiences or otherwise, to express these qualities.

For instance, a Magnet’s quality is universally likened to glue, while its capacity to attract is culturally rendered as magical. Similarly, the shared concavity of a Concave Lens and a mountain is a universal observation, whereas its resemblance to the Chinese character 凹 is culture-specific. Vapour’s invisibility equates it universally to air and culturally to invisible entities. For abstract concepts, Buoyancy’s capacity to make objects float is universally compared to the uplift of a hand and culturally to the effect of Gravity. Energy’s omnipresence in the body is universally compared to blood and culturally to electricity.

Table 4.27 Examples of Using Universal and Culture-Specific Metaphor to Reflect Intrinsic Property

Concept	**Metaphor Type**	**Participant Number**	**Examples**
Magnet	Universal Metaphor	5722	*Magnet is like glue, because it can stick something.*
	Culture-specific Metaphor	3719	*Magnet is like magic, because it can stick something.*
Concave Lens	Universal Metaphor	5507	*Concave Lens is like a mountain, because they all have concave shape.*
	Culture-specific Metaphor	4702	*Concave Lens is like character “凹”, because they all have concave shape.*
Vapour	Universal Metaphor	3528	*Vapour is like air, because it cannot be seen.*
	Culture-specific Metaphor	3711	*Vapour is like invisible people, because it cannot be seen.*
Mercury	Universal Metaphor	5317	*Mercury is like poison, because it is toxic.*
	Culture-specific Metaphor	4527	*Mercury is like monster, because it is toxic.*
Circuit	Universal Metaphor	5727	*Circuit is like rope, because they can be connected to each other.*
	Culture-specific Metaphor	3506	*Circuit is like code, because they can be connected to each other.*
Gravity	Universal Metaphor	5325	*Gravity is like stone, because it can press objects.*
	Culture-specific Metaphor	4301	*Gravity is like air pressure, because it can press objects.*
Buoyancy	Universal Metaphor	4815	*Buoyancy is like hand, because it can make things flow.*

	Culture-specific Metaphor	3707	*Buoyancy is like Gravity, because it can make things flow.*
Energy	Universal Metaphor	4501	*Energy is like blood, because it can exist in our body.*
	Culture-specific Metaphor	4817	*Energy is like electricity, because it can exist in our body.*

The delineation of extrinsic properties follows a similar pattern; they can be articulated through two distinct metaphorical types. In this instance, universal metaphors account for 87.5% of expressions, while culture-specific metaphors constitute 12.5%. Examples of this can be found in the subsequent table.

Table 4.28 Examples of Using Universal and Culture-Specific Metaphor to Reflect Extrinsic Property

Concept	**Metaphor Type**	**Participant Number**	**Examples**
Magnet	Universal Metaphor	5722	*Magnet is like stone, because it is hard.*
	Culture-specific Metaphor	3719	*Magnet is like letter U, because they have the same shape.*
Concave Lens	Universal Metaphor	5704	*Concave Lens is like a toy, because we like to play it.*
	Culture-specific Metaphor	4725	*Concave Lens is like a clown, because it can make people laugh.*
Vapour	Universal Metaphor	3528	*Vapour is like a pot, because it can generate water.*
	Culture-specific Metaphor	3711	*Vapour is like elf, because it is everywhere.*
Mercury	Universal Metaphor	5317	*Mercury is like water, because it can also move.*
	Culture-specific Metaphor		
Circuit	Universal Metaphor	5727	*Circuit is like hand, because it can make machine work.*
	Culture-specific Metaphor	3506	*Circuit is like Energy, because it can make light works.*
Gravity			
Buoyancy			
Energy	Universal Metaphor	4501	*Energy is like friend, because it can erase our exhaustion.*

	Culture-specific Metaphor	4411	*Energy is like god, because it can make things move.*

As extrinsic property-related expressions are less numerous and more varied, there are no examples like those for intrinsic properties where the same property is described by different types of metaphors. However, within the same concept, there is a phenomenon where different extrinsic properties of a concept are described by different universal metaphors. For instance, a Magnet is likened to stone due to its hardness and to the letter 'U' for its shape. A Concave Lens is compared to a toy as it is playful, and to a clown for its capacity to entertain. In the case of a Circuit, it is likened to blood for its role in powering machines and to Energy for its ability to illuminate. Energy is personified as a friend that can alleviate exhaustion and as a deity capable of initiating movement. Notably, for Mercury, there are no culture-specific metaphors used to describe extrinsic properties. Likewise, for Gravity and Buoyancy, due to the absence of extrinsic properties, there are no examples to present.

Misconceptions in the study are also linked with both types of metaphorical expressions. Within the 339 metaphors related to misconceptions, a predominant majority, 97.3%, are universal metaphors, while a mere 2.7% are culture-specific metaphors. Examples are provided in the following table.

Through these examples, it is observable that there are no misconceptions associated with Magnets, hence no examples were provided. For the other concrete concepts, such as Concave Lenses, Vapour, and Mercury, misconceptions are conveyed exclusively through universal metaphors, with no culture-specific metaphors employed. However, misconceptions related to the remaining four abstract concepts are expressed through both metaphor types.

Table 4.29 Examples of Using Universal and Culture-Specific Metaphor to Reflect Misconception

Concept	**Metaphor Type**	**Participant Number**	**Examples**
Magnet			
Concave Lens	Universal Metaphor	5704	*Concave Lens is like a lighter, because it can set fire.*
	Culture-specific Metaphor		
Vapour	Universal Metaphor	3528	*Vapour is like white paint, because it is white.*
	Culture-specific Metaphor		
Mercury	Universal Metaphor	5317	*Mercury is like air, because it is transparent.*
	Culture-specific Metaphor		
Circuit	Universal Metaphor	5727	*Circuit is like sweater, because it can generate electricity.*
	Culture-specific Metaphor	3506	*Circuit is like music notes, because they are all very active.*
Gravity	Universal Metaphor	5325	*Gravity is like hand, because it can make us fly.*
	Culture-specific Metaphor	4815	*Gravity is like imperial power, because it is heavy.*
Buoyancy	Universal Metaphor	4815	*Buoyancy is like balloon, because it is light.*
	Culture-specific Metaphor	5325	*Buoyancy is like oxygen, because they can all flow up.*
Energy	Universal Metaphor	4501	*Energy is like fire, because it is really hot.*
	Culture-specific Metaphor	4411	*Energy is like electricity wave, because it has power.*

This structured breakdown provides a clear perspective on how different metaphor types are proportionally distributed when discussing intrinsic properties, extrinsic properties, and misconceptions within universal and culture-specific contexts. The primary insight from this analysis is that both universal and culture-specific metaphors can be employed to express the intrinsic and extrinsic properties of scientific concepts, as well as to convey misconceptions. For all types of understanding, participants selected objects or entities with characteristics like the concept under study as the source domain for mapping. The essence of this metaphorical mapping lies in identifying a shared characteristic between the concept and another object. Regarding culture-specific metaphors, students map the properties of source domains that they have learned within their sociocultural context to the property of scientific concepts.

Although both can be utilised for description, the proportions of universal metaphors and culture-specific metaphors vary for different understandings. In the case of intrinsic and extrinsic properties, the proportion of culture-specific metaphors is relatively high compared to the average. However, misconceptions are more inclined towards the use of universal metaphors.

4.4.3 Distribution of Six Combinations Across Three Grade Groups

This section investigates the correspondence between conceptual understanding types and universal metaphors across three Grade groups. Relevant data is presented in the table below. It delves into the interplay between conceptual understanding types and metaphor preferences across various academic levels. It shows that the occurrence of culture-specific metaphors for intrinsic properties climbs from 7.2% in Grade 3 to 15.6% in Grade 5. Similarly, for extrinsic properties, the percentage increases from 10.3% in Grade 3 to 17.9% in Grade 5.

Table 4.30 Distribution of Metaphor and Conceptual Understanding Type across Grade Groups

Grade	**Conceptual Understanding Type**	**Metaphor Type**	
		Universal Metaphor Number (%)	Culture-Specific Metaphor Number (%)
Grade 3	Intrinsic Property	336 (92.8)	26 (7.2)
	Extrinsic Property	78 (89.7)	9 (10.3)
	Misconception	120 (97.6)	3 (2.4)
Grade 4	Intrinsic Property	365 (91.7)	33 (8.3)
	Extrinsic Property	127 (88.2)	17 (11.8)
	Misconception	130 (95.6)	6 (4.4)
Grade 5	Intrinsic Property	200 (84.4)	37 (15.6)
	Extrinsic Property	46 (82.1)	10 (17.9)
	Misconception	80 (1.00)	0 (0.00)

Conversely, the representation of misconceptions through universal metaphors remains consistently high across all grades, consistently outstripping the 91.3% average. In Grade 3, 97.6% of misconceptions were communicated using universal metaphors, a figure that slightly diminished to 95.6% in Grade 4. Grade 5 marks a noteworthy trend where 100% of the misconceptions were depicted with universal metaphors, indicating a total absence of culture-specific metaphors within this category of understanding.

4.4.4 Distribution of Six Combinations Across Research Concept

This section investigates the correspondence between conceptual understanding types and universal metaphors across research concepts. Relevant data is presented in the table below.

Table 4.31 Distribution of Metaphor and Conceptual Understanding Type across Research Concepts

Concept	**Conceptual Understanding Type**	**Metaphor Type**	
		Universal Metaphor Number (%)	Culture-Specific Metaphor Number (%)
Magnet	Intrinsic Property	307 (92.8)	24 (7.2)
	Extrinsic Property	21 (75.0)	7 (25.0)
	Misconception	0 (0.0)	0 (0.0)
Concave Lens	Intrinsic Property	35 (83.3)	7 (16.7)
	Extrinsic Property	5 (45.5)	6 (54.5)
	Misconception	10 (1.0)	0 (0.0)
Vapour	Intrinsic Property	158 (92.9)	12 (7.1)
	Extrinsic Property	33 (97.1)	1 (2.9)
	Misconception	20 (1.0)	0 (0.0)
Mercury	Intrinsic Property	116 (90.6)	12 (9.4)
	Extrinsic Property	86 (98.9)	1 (1.1)
	Misconception	9 (1.0)	0 (0.0)
Circuit	Intrinsic Property	59 (95.2)	3 (4.8)
	Extrinsic Property	54 (94.7)	3 (5.3)
	Misconception	67 (98.5)	1 (1.5)
Gravity	Intrinsic Property	69 (78.4)	19 (21.6)
	Extrinsic Property	0 (0.0)	0 (0.0)
	Misconception	81 (95.3)	4 (4.7)
Buoyancy	Intrinsic Property	120 (90.9)	12 (9.1)
	Extrinsic Property	0 (0.00)	0 (0.00)
	Misconception	131 (97.8)	3 (2.2)
Energy	Intrinsic Property	37 (84.1)	7 (15.9)
	Extrinsic Property	52 (75.3)	18 (25.7)
	Misconception	12 (92.3)	1 (7.7)

This table allows us to see that within all concepts, the proportion of universal metaphors used to describe misconceptions exceeds the average of 91.3%. Furthermore, for all concrete concepts, students did not employ culture-specific metaphors to depict their misconceptions. In contrast, for the other two understanding types, intrinsic and extrinsic properties, the usage of metaphor types varies across different concepts.

4.5 Interview Analysis Findings

This section presents the findings derived from the interview data. Three questions were asked during the interview to investigate participants' metaphor generation process for scientific concepts:

1. What do you think can impact the specific words you choose to describe your explanation?
2. For concepts in questionnaire, how do you build your understanding of it?
3. What challenges did you encounter when you answered the questionnaire?

The primary inquiry of the first interview question is focused on exploring the driving factors behind participants choosing their source domains in questionnaires. The second question is designed to explore how participants build their understanding of scientific concepts in this research. Through these two questions, participants from three Grade groups provided insights into their metaphor production process. At the end of the interview, participants expressed the difficulties they encountered in this process through the last question.

After the transcription of the interviews, a thematic analysis was conducted. Two principal themes emerged from this process:

1. **Use of Personal Experiences to Generate Metaphors**: This theme refers to participants discussed using their direct embodied experiences to produce metaphors when finishing the questionnaire in this study. These experiences span broadly and also pertain to personal engagements within different settings.

2. **Use of External Sources to Generate Metaphors**: This theme reflects how participants used information gathered from various resources to create metaphors while completing the questionnaire in this study.

This section will commence with a synopsis and then subsequently delineate each theme.

4.5.1 Theme 1: Use of Personal Experiences to Generate Metaphors

The first theme refers to the participants' discussions surrounding their direct embodied experiences, and how they contribute to the creation of metaphors on scientific concepts within questionnaires. During interviews, students noted two important functions of these embodied experiences: one is the formation of their conceptual understanding, and the other is the influence on their selection of source domains.

> *I know this because I have seen it myself. (Participant 4711)*
> *Touching a Magnet and feeling its hardness, and then seeing it attract objects, proves its Magnetic attraction. (Participant 3501)*
> *Without actual experience, you cannot create this metaphor. (Participant 4129)*
> *It is related to my life experiences. I say an octopus because he has touched it before. (Participant 3307)*

The first two examples suggest that participants believe their observation of real life experiences and personal manipulation lead to an understanding of the nature of scientific concepts. The next two examples mentioned that these first-hand experiences also influenced their selection of the source domain for metaphors. In the answers of Participant 4129, the participant highlighted personal experience as a necessary factor for completing metaphors. In the last example, the necessity of personal experience is further detailed using the example of an octopus as source domain.

In the examples given above, participants did not specifically mention the environments where these experiences occurred; however, some emphasised the context in which they took place. From their responses, it is evident that for the third to fifth grade participants in the study, school and home environments were the primary sources of their embodied experiences.

> *My mother bought me a science experiment kit, and by following the manual, I came to understand. (Participant 3701)*

> *In the fourth grade, we had a toolkit that included a Magnet. If a school didn't provide this, I might miss out and not recall it. (Participant 5323)*

In these two examples, participants explicitly stated the context of their embodied experiences—one in the family context, and the other in the school context. Both statements underline the belief that it is the family and school environments that facilitate physical experiences, thereby fostering an understanding of scientific concepts.

From the aforementioned examples, it can be seen that participants across all grades emphasised the significance of embodied experiences during the interviews. However, among the third-grade participants, responses predominantly highlighted their own personal experiences, whether derived from their family or school. In contrast, fourth and fifth graders also stressed in their interviews the awareness that everyone's experiences and their perceptions of these experiences are, to a large extent, diverse.

> *So, like, even if we go through the same thing, my teacher and I might not get it the same way. The stuff that sticks in our brains is different, right? So when it's time to answer questions, maybe some things pop up in my mind, and maybe some things just don't. (Participant 4303)*
> *The reason we think differently is that we've lived through different stuff. That's why we don't get things the same way. People who've been through something and people who haven't are totally gonna have different ideas about it. (Participant 5313)*

In the examples provided, fifth-grade participants were the first to realise that their embodied experiences differed from those of another participant. They also recognised that these differences contributed to their distinct understandings of scientific concepts and that different embodied experiences could lead to varying interpretations of scientific subjects. Fourth-grade students' responses emphasised that even identical embodied experiences may not have the same impact on different individuals.

Beyond the varied understandings of embodied experiences across grades, the analysis also revealed that all mentioned embodied experiences in interviews related only to the four concrete concepts explored in the study, for instance:

> *I touched a Magnet, so I know it’s hard. (Participant 3513)*
> *Can’t we always see the shape of a Concave Lens? It’s just like a spoon. (Participant 4719)*
> *We come across steam every day in life, so I just know it's really hot. (Participant 4121)*
> *Mercury is in thermometers, and it is silver-coloured. (Participant 5307)*

In describing the four concrete concepts above, students detailed how they articulate the characteristics of these through personal experiences. However, no participants mentioned how they utilised embodied experiences to comprehend the abstract concepts in the study, such as Gravity and Buoyancy.

Overall, this theme addresses the participants' direct interactions with the physical world and the manner in which these embodied experiences inform their metaphorical representations of scientific concepts, contributing to their conceptual understanding and selection of source domains. These experiences primarily originate from home and school settings. Moreover, as students age, they progressively acknowledge the diversity of experiences among individuals, which can lead to variations in the learning of scientific concepts.

4.5.2 Theme 2: Use of External Sources to Generate Metaphors

This theme represents the information participants acquired through diverse discourse forms.

During interviews, participants from Grades 3, 4, and 5 emphasised how external sources influences their conceptualisation and metaphorical expressions when completing questionnaires. A Grade 5 participant stated:

> *When I was younger, I really wanted to know why Magnets could stick to stuff and what made the ends of them pull together or push apart. So, I looked it up on the internet and found out lots about how Magnets work and what else they can do. (Participant 5711)*

This excerpt illustrates the essence of the theme: how accessible information influences the participant's conceptual understanding of scientific concepts, such as

Magnetism. Moreover, this type of accessible information obtained from various sources not only expands the participants' comprehension of the specified concepts but also enriches their metaphorical language, as reflected in the articulation:

> *When my teacher uses some words in class, I start using them too, and it makes the way I talk even better. (Participant 4703)*

The discourse thus illustrates how educational content assimilated from authoritative figures like teachers can influence participants' choice of source domain in metaphor construction, suggesting a transference of terminological preference from the educator to the learner.

Concerning these external sources, students mentioned a variety of different origins. Among these, the information acquired from school science education was most frequently cited.

> *My foundational understanding of scientific concepts is largely from science textbooks. (Participant 3315)*
> *The teacher made it clear in the class, so now I know it. (Participant 4622)*
> *I remember when I was in second grade, we had a whole unit about Buoyancy. (Participant 5207)*

From these instances, it is evident that school learning offers an external resource encompassing all facets of school science education, acknowledged by students across the third, fourth, and fifth grades. Additionally, the examples demonstrate its utility in elucidating abstract scientific concepts.

The second participant indicated that their family was the external source of information. Within this category, respondents identified their families as the source of scientific knowledge. Most referenced learning through familial interactions, with numerous students attributing their ideas to remarks such as “what my mom told me”. This particular phrase recurs across the narratives of third, fourth, and fifth graders. A student in fifth grade distinctively remarked on the variance in information received from family among different individuals.

> *For example, some parents, they specialize in this area, so when you ask them questions, they can give you detailed answers. This is what we think of as different influences, I guess. (Participant 5517)*

In this expression, the Grade 5 student suggests that different family environments, such as parents’ occupations, lead to varying responses they can provide when answering students' questions about science. This may influence students’ understanding of scientific concepts in different ways.

Lastly, the students also mentioned external reading as an aid to generating metaphors. The internet was the most discussed source among them. From Grade 3 to Grade 5, students at each grade level mentioned reading information online as a means to their understanding of the characteristics of scientific concepts. Related expressions include “*My iPad showed that Mercury is toxic*” and “*I read online that Mercury is described as resembling silver*”, further illustrating the impact of online information on the selection of source domains and understanding of scientific concepts.

However, interviews reveal that third graders' familiarity with external reading sources is less comprehensive than that of fourth and fifth graders. Apart from internet resources, they did not mention other sources. In contrast, fourth and fifth graders referred to reading various popular science books, such as *Hundred Thousand Whys*, to learn scientific concepts. This led to moments during questionnaire completion when they felt unsure about which words to use to describe their experiences:

> *I can sort of find the idea, but I just can’t remember the exact word for it. I can’t make it specific enough to write down. (Participant 3509)*
> *It’s like when you don't know how to fill in the blank because it feels super similar to something, but you can't remember what it's called. (Participant 3717)*

In these statements, two Grade 3 students expressed that while they understand scientific concepts and are aware of their properties, they lack sufficient external resources and literacy, preventing them from finding appropriate source domains to articulate their understanding.

Overall, this theme of Information pertains to the influence of various sources of information on the participants’ process of metaphor generation. The pathways identified in the study are reflected through three sub-themes: information gained through online and offline reading, family, and the school environment.

4.6 Findings Summary

This section summarises the key findings related to the analysis of metaphors within the study.

For the analysis of the questionnaire, the initial step involved coding for metaphor identification to ascertain which responses contained complete metaphors. A comprehensive analysis of responses from 2,159 student participants highlighted a significant utilisation of metaphorical expressions, with 1,623 responses (75.2%) being classified as valid metaphors.

Subsequently, these 1,623 metaphors underwent further coding for metaphor type analysis. This revealed a predominance of Universal Metaphors, totalling 1,482 and accounting for 91.3% of all valid metaphors, while Culture-Specific Metaphors were less frequent, with 141 instances comprising 8.7% of the total. Across all grades and concepts within the study, Universal Metaphors were more common. Notably, from grades three to five, there was a marked increase in the proportion of Culture-Specific Metaphors. Among the concepts examined, convex lenses and Energy had the highest proportions, exceeding 20%.

The examples also showed that Universal Metaphors mainly drew from physical entities and body parts as their source domains. In contrast, the source domains for Culture-Specific Metaphors included three categories: abstract concepts, non-Physical entities, and language characters.

All metaphors were also coded for types of conceptual understanding: intrinsic property, extrinsic property, and misconception. It was found that among all metaphors, Intrinsic Properties were most frequent at 61.43%, followed by Extrinsic Properties at 20.89%, with Misconceptions being the least frequent at 17.68%. No significant differences in these proportions were observed across different grades, while significant variations were found across different concepts. Excluding Mercury, the intrinsic properties of the other three concrete concepts significantly surpassed the average of 61.4%. Magnets, in particular, had an intrinsic property percentage over 30% above the average. Moreover, their percentages for extrinsic properties and misconceptions were below the average. For abstract concepts—Circuit, Gravity, Buoyancy, and Energy—all had intrinsic property percentages considerably below the average, particularly Circuits and Energy, which were about half of the average. Meanwhile, their percentages for misconceptions, excluding Energy, were several times higher than the average of 17.68%, specifically 36.4%, 49.1%, and 50.4%. Additionally, the abstract concepts’ extrinsic properties were highly distinctive, with two concepts, Circuit and Energy, exceeding the average, and Energy's being more than double. In contrast, the extrinsic property percentages for Gravity and Buoyancy were 0, unique compared to all other concepts.

Intrinsic property was understood as concept properties not related to the environment, manifesting in two ways: properties inherent to the concept itself and the concept’s constant effects on the external world. Extrinsic property indicates an understanding related to the concept but influenced by other factors, often associated with participants’ personal experiences and focus on individual entities. Misconception included understandings diverging from scientific interpretations of these concepts and, for abstract concepts, attributions of properties not associated with abstract concepts.

The study further combined conceptual understanding types with metaphor types, and a Chi-Square Test indicated a significant correlation between them. With three conceptual understanding types and two metaphor types, six different combinations emerged in the study. This analysis underscored that both universal and culture-specific metaphors facilitate the expression of intrinsic and extrinsic properties of scientific concepts and the conveyance of misconceptions. For all understanding types, participants chose objects or entities with similar characteristics to the concept under study as the source domain for mapping.

However, the proportions of these six combinations varied. For all metaphors, the proportion of culture-specific metaphors was relatively high for intrinsic and extrinsic properties but leaned towards universal metaphors for misconceptions.

Across different grades, the representation of these combinations varied. For intrinsic and extrinsic properties, the proportion of culture-specific metaphors increased from grades three to five. Conversely, the representation of misconceptions through universal metaphors remained consistently high across all grades, surpassing the average of 91.3%. Regarding concepts studied, the use of universal metaphors to describe misconceptions exceeded the average. Furthermore, for all concrete concepts, students did not use culture-specific metaphors for their misconceptions. However, for intrinsic and extrinsic properties, metaphor use varied across different concepts.

This chapter additionally sets forth the outcomes of a thematic analysis from interviews, where two themes emerged: the Use of Personal Experiences to Generate Metaphors and the Use of External Sources to Generate Metaphors, emphasising the diverse methods by which participants create metaphors in this study.

These findings will be further discussed in the next chapter.

5 DISCUSSION

This chapter will discuss the results presented in the preceding chapter and address the main question of this research along with the two sub-questions. Sections 5.1, 5.2 and 5.3 respond to the main research question by exploring how the conceptual understanding of scientific concepts is related to embodied experiences and situated sociocultural contexts. Section 5.4 addresses the two sub-questions, focusing on the connection between metaphor and science education.

5.1 Conceptual Understanding and Embodied Experience

For the main research question: *'How are students' understandings of scientific concepts related to their embodied experiences and sociocultural context?'*, this section focuses on one aspect, the relationship between embodied experiences and conceptual understanding. Section 5.1.1 and Section 5.1.2 provide details on this relationship. Subsequently, Sections 5.1.3 highlight the importance of resources for metaphor generation. Section 5.1.4 critically evaluates how embodied experiences can lead to misconceptions of scientific concepts.

5.1.1 Embodied Experience Assists in Constructing Conceptual Understanding

Many studies have explored the role of embodied experience in conceptual understanding. Research has demonstrated that physical experiences can enhance science learning by activating sensorimotor brain systems, which in turn aids in grasping scientific concepts (Kontra et al., 2015). This suggests that embodied experience can be used to develop a deeper understanding of scientific ideas.

Studies in the science education field have highlighted how students utilise the cognitive and conceptual aspects of their everyday experiences to either support or challenge their understanding of scientific concepts (Kervinen et al., 2020). For this function, how it works for concrete and abstract concepts is different. For concrete concepts having physical forms, students can interact directly with them and comprehend their characteristics through direct interaction. This role is shown in the interviews of this study. During interviews, students elaborated on how embodied experiences, such as touching Magnets or feeling the heat from steam, led to an understanding of concrete concepts. This research also discovered that the conceptual understanding derived from these direct embodied interactions with concrete concepts is not always accurate, which will be discussed in the following section.

In contrast, how embodied experiences facilitate the construction of conceptual understanding for abstract concepts differs significantly. Analysis results in this study suggest that embodied experiences contribute to understanding abstract concepts through objectification, which involves transforming complex and abstract scientific concepts into familiar, conventional, and simplified entities that are perceived as tangible elements of reality rather than abstract notions (Wibeck et al., 2017). As mentioned in Section 4.3, the majority of conceptual understandings identified in this research concern the status of scientific concepts or their consistent effects on the external world. To construct these understandings, participants in this study objectify abstract concepts into entities, and their status as well as their interactions with the external world are interpreted through embodied experiences, then form the conceptual understanding of the abstract concepts.

For example, in questionnaires, in the expression that *Gravity causes objects to move*, Gravity is objectified as an entity that can produce effects on the external environment, and its property is the ability to cause movement of other objects, which is based on embodied experiences. In the expression that *Energy is very hot*, Energy is objectified into an entity, and the heat becomes a property of the concept of Energy, which is also based on embodied experiences. Through objectification, students' own embodied experiences can be utilised to construct an understanding of scientific concepts.

In summary, direct interaction and objectification are two key methods by which students utilise embodied experiences to construct conceptual understanding. This has important implications for the role of embodied experience in science education. Diverse embodied perspectives are recognised to strengthen arguments in science education research and enhance the potential of embodied cognition in educational practices (Kersting et al., 2021). Numerous studies have investigated how to leverage embodied experiences to improve learning outcomes in scientific knowledge (Johnson-Glenberg et al., 2014), argumentation (Tang, 2022), and engagement in classrooms (Kim and Tscholl, 2021). Research on technology-enabled embodied learning environments has analysed embodiment features in educational settings to enhance conceptual understanding and learning outcomes (Li and Xu, 2021). However, detailed descriptions of how embodied experiences construct conceptual understanding, particularly in extracurricular settings, are lacking. Addressing misconceptions and promoting conceptual understanding are highlighted as essential in science education to foster scientific literacy (Addido et al., 2022). This study summarises these two methods of embodied experience in constructing conceptual understanding, providing additional insights in this research area.

5.1.2 Embodied Experience Assists in Expression of Conceptual Understanding

Another role of embodied experience in conceptual understanding emphasised by this study is in facilitating the expression of conceptual understanding. The research suggests that embodied experiences and universal metaphors may be important for students across all grade levels in expressing their understanding of scientific concepts. It is shown that embodied experiences play an important role in both constructing conceptual understanding and the use of language in scientific contexts.

The use of scientific language is fundamental in science education, influencing both instructional practices and student learning experiences. Proficiency in scientific language is crucial for accurately and precisely communicating complex scientific ideas, highlighting the importance of language in science education (Dimenäs, 2018). Much research in the field of science education has already been conducted from a sociolinguistic perspective, including studies on language policy and ecology (Lee, 2005), language-inclusive ideologies in the classroom (Lemmi et al., 2019), and translanguaging pedagogies (Palmer et al., 2014). The findings of this study, which emphasise the role of embodied experience in scientific expression, may offer new possibilities for exploring scientific language.

Recent studies have suggested that integrating effective embodied experiences in the classroom can enhance mastery of scientific language. El-Sharif (2023) explores the use of embodied metaphors in language and communication, highlighting the impact of sensorimotor experiences on linguistic expressions and conceptualisations. Cleeve Gerkens et al. (2023) further demonstrate that embodied and role-based experiences can foster academic language development among middle primary students. These experiences enable students to transition from their initial encounters with abstract academic language to full ownership of this language through verbal and written reflection on the embodied event. In this research, the transformation is manifested by expressing the complex properties of scientific concepts through familiar, accessible entities using metaphors, thereby enhancing students’ expression of scientific concepts and improving their use of language in scientific contexts. This result aligns with research on this trend and further presents how embodied experiences are connected with students' language use in the scientific context.

5.1.3 Accessible Objects Are the Main Resources for Generating Embodied Experiences

The first main result of this study builds on the prior research presented in Section 2.1.3 that underscored the significance of embodied experience in science education, emphasising the particular importance of the embodied experiences generated from interactions between students' bodies and accessible objects in everyday life for the understanding of scientific concepts. The role of these experiences is manifested as students' comprehension of the affordance of accessible objects through embodied experiences and their application to their understanding of scientific concepts. This section will discuss this argument in detail.

The prevalent use of this type of embodied experience is substantiated in two respects in this study. Firstly, Section 4.2.2 details instances of source domains in universal metaphors as identified by participants, where a substantial proportion pertain to tangible objects encountered in daily life. In the construction of metaphors, participants utilised the characteristics of these objects to map onto the similar properties of scientific concepts. This trend is consistent across the various grade levels and scientific concepts explored in this study. Secondly, during interviews, participants provided examples of how their interaction with, and manipulation of, these objects led to embodied experiences that, in turn, contributed to the evolution of their scientific conceptualisation.

This appreciation of embodied experience, which emerges through interaction with objects, aligns with the recently emphasised current paradigm of materialism in embodied science education (Tang, 2024). It also highlights the impact of material objects and physical bodies on cognition within a scientific context (Hetherington et al., 2018). From this perspective, our ontological understanding of nature and the epistemology of how we comprehend it are profoundly influenced by our interactions with material objects. This research demonstrates that students can generate embodied experiences through various interactions within everyday scenarios. Such experiences include observation and tactile involvement, extending to participatory involvement in object interaction activities, such as playing football. These experiences primarily facilitate two types of understanding: an awareness of an object’s status, including its colour and form, as well as its effects and functions. In this study, most conceptual understanding identified—including intrinsic properties, extrinsic properties, and misconceptions—also pertains to the scientific concepts’ status or their impacts on the external world. When constructing metaphors, the similarity between the properties of objects and concepts can be correlated according to the results of this research. This demonstrates the perspective of materialism, indicating that interaction with objects forms the foundation for constructing and understanding scientific concepts.

The significance of embodiment and materiality has been investigated a lot in contemporary research, notably through video and multimodal analyses of classroom recordings, wherein the body and material objects are conceptualised as integral modes and media in the creation, assessment, and refinement of representations (Wilmes et al., 2024). However, the materialism emphasised in this study diverges from the majority of investigations in this field. Hetherington et al. (2018) conducted a systematic review of studies related to practical work between 1998 and 2018, revealing that the vast majority centred on the teaching and investigation of “recipe-style” laboratory activities within laboratory environments, along with the importance and efficacy of practical work. Although there is extensive research on the crucial role of hands-on experience and direct observation in students’ understanding of scientific phenomena within the classroom, there is scant research exploring the role of the body and materiality in constructing the conceptual understanding of scientific concepts through interaction with everyday accessible resources.

Given the fundamental role of materiality in human interaction and meaning-making, material resources should be treated not merely as a component of laboratory work for science instruction but conceptualised as integral to human culture and knowledge (Milne and Scantlebury, 2019). This study aptly addresses this gap, placing greater emphasis on materialism in everyday life when children engage with accessible objects. As mentioned before, all embodied experiences associated with accessible objects in this study are not designed purposefully for certain pedagogical interventions but from students' spontaneous everyday contexts. This understanding of embodied experiences and materiality offers a more holistic approach to science education.

Additionally, this type of embodied experience can also contribute to science learning. As previously noted by (Tang, 2024), students' use of embodied experiences with accessible objects discussed in this section is categorised as a form of recall of their past embodied experiences, rather than real-time usage in a situated classroom context. Tang particularly emphasises the importance of this category, recalling material, viewing it as critical for providing a multi-timescale analysis that interlinks past, present, and future events involving material interaction. Analysing science classrooms from Grades 5 to 10, Tang found that recalling previous everyday embodied interactions frequently occurs in the classroom when constructing scientific knowledge. Recognising these students' prior knowledge and assumptions about scientific concepts is therefore crucial in instruction to support effective learning (Versteeg et al., 2021).

Results in this research have shown the efficacy of this type of embodied experience among students, with over 1482 of their responses successfully employing their formal embodied experiences to explain complex scientific concepts. This has crucial implications for educational practices, indicating that technological investments may not be essential for effective learning and could influence curriculum design and instructional methods. Apart from its effects being questioned (Goldinger et al., 2016), a notable limitation of educational technology is its potential to exacerbate educational inequalities, especially among learners from low socioeconomic backgrounds. The current study advocates the use of everyday embodied experiences for concept learning and embodied science education, which may lead to more inclusive educational strategies implementable without complex technological resources, thereby expanding access to high quality science education.

In conclusion, the first result of the current study highlights the significance of embodied experiences derived from student interactions with accessible objects in everyday life. This viewpoint suggests that, beyond crafting materially and embodiment-rich contexts within the classroom, embodied science education should also more rigorously examine how students' daily engagement with accessible objects can be leveraged to enhance science learning.

5.1.4 Embodied Experience Can Lead to Misconceptions

The analysis indicates the importance of embodiment in conceptual understanding, but Messig and Groß (2018) also discussed how alternative conceptions in plant nutrition may originate from embodied experiences related to the human body, highlighting the influence of personal bodily experiences on the formation of misconceptions. This means that a judicious approach to embodiment is crucial, given its potential for both positive and negative impacts on the comprehension of scientific concepts. Consequently, careful consideration is necessary when incorporating embodied experiences into conceptual understanding. This study identifies that embodied experiences contribute differently to misconceptions concerning concrete and abstract concepts.

First, this study demonstrates that subjective embodied perceptions may contribute to misunderstandings of scientific concepts due to issues of generalisation. For example, participants sometimes applied their experiences with specific tangible objects, such as a single Magnet, noting its weight or colour, and generalised these attributes to Magnets as a category. Similar patterns were observed with other concrete concepts, such as Concave Lenses and Mercury. Students often fail to grasp the essential, shared properties of these scientific concepts, focusing instead on superficial aspects. While these understandings are classified as extrinsic properties within this study, if not addressed with caution, they have the potential to foster misconceptions among students.

In addition to the generalisation issue, research has proposed that when individuals rely on their everyday observations and experiences to make sense of scientific concepts, there is a risk of developing misconceptions due to the limitations and inaccuracies inherent in this observation (Antink-Meyer and Meyer, 2016). This study shows that students often observed or engaged with these phenomena without fully comprehending the underlying scientific principles. For instance, in questionnaires, participants mentioned everyday phenomena such as steam causing explosions or Magnets attracting objects and articulated these as properties of the scientific concepts. Although these interpretations are classified as extrinsic properties in this research, these understandings may pose challenges in grasping the role of pertinent scientific concepts without appropriate educational intervention. Furthermore, these everyday embodied experiences can sometimes directly lead to misconceptions. Participants in this research expressed the belief that *Vapour is white*. Based on the common everyday observation that water droplets appear white, leading to students' misconception about its nature.

The issues of overgeneralisation and the impact of everyday experiences are fundamentally linked to the level at which students understand these embodied experiences. In chemistry education, Johnstone's (1982) level-based description of external representations proposed that chemical knowledge is generated and communicated at three different levels: the symbolic, submicro and macro levels (Niebert, 2015). External representations on the macro level describe learning activities focussing on empirical properties of chemicals that are perceptible (e.g.mass, density, concentration, pH and temperature). Submicroscopic external representations are models or diagrams to explain macroscopic phenomena. Symbolic external representations involve conventions to represent atoms or molecules. This triplet of external representations has served as a framework for many studies and inspired the work of chemistry teachers and researchers as well (Gilbert and Treagust, 2009).

In this research, participants’ conceptual understanding is categorised into Extrinsic Properties, which are understandings related to the concept but influenced by other factors, and are all situated at the macro level. They were often associated with specific individual entities and participants’ personal experiences. For these understandings, if the appropriate approach is provided it can be used for promoting science learning (Niebert, 2015). Otherwise, it may lead to misconceptions, as demonstrated in this study.

These issues must be given serious attention, as such misconceptions are common and difficult to change. Within the domain of science education, research has demonstrated that misconceptions, which are closely related to everyday experiences may appear more convincing and engaging than scientifically accurate explanations, leading individuals to hold onto these misconceptions despite contradictory evidence and more difficult to change (Kulgemeyer and Wittwer, 2023). Research has also proved that the reliance on traditional teaching methods that do not incorporate embodied experiences may lead to surface-level understanding or misconceptions about abstract physics principles (Jamrozik et al., 2016). Consequently, it is essential to incorporate more detailed explanations of pertinent embodied experiences when presenting scientific concepts. Additionally, misconceptions that stem from embodied experiences require greater scrutiny and intervention. This study further emphasises this point, demonstrating that merely integrating everyday embodied experiences is insufficient; it is also crucial to consider their potential impacts.

For abstract concepts, the impact of embodied experiences differs. In these cases, students may only observe the macroscopic outcomes, not the internal mechanics of the concepts. For example, learners might understand that an electric Circuit conducts current but are unable to directly observe the current, merely its manifestations. This gap in embodied experience is evident in this study’s lack of descriptions concerning the extrinsic properties of concepts like Gravity and Buoyancy, due to the students’ inability to directly observe them. Additionally, in the interviews, no students discussed how embodied experiences shaped their understanding of abstract concepts. This lack of engagement with everyday embodied experiences has led to inaccuracies in this research, such as the misrepresentation that *Circuit is in motion*. In the same vein, students observing objects floating may not perceive the force of Buoyancy, leading to the misconception that *Buoyancy rises*.

In biology, it is proposed that many difficulties of scientific concepts are due to this kind of non-observable phenomena (Subramaniam, 2014). This is also important in the physics field. Abstract concepts in physics often lack direct embodied experiences, as they are not readily observable or tangible in the physical world. Physics deals with concepts such as Energy, Force, and Fields, which do not have concrete physical manifestations that can be directly perceived through the senses. This lack of direct sensory experience with abstract physics concepts can pose challenges for learners in understanding and internalising these ideas (Borghi et al., 2017).

Last, objectification, a primary method through which embodied experiences construct an understanding of abstract concepts, may also lead to misconceptions. Research has shown that objectification is widely employed by many teachers and students. For example, common usage of this word in the surveyed documents suggests that its meaning is unproblematically familiar to most readers. Furthermore, the verbs that tend to accompany the word “concept(s)”, such as “understand”, “know”, “have”, “use”, “apply”, and “develop”, seemingly imply that a concept is a thing or object that one can recognise, acquire, and possess (Kuipers et al., 2008). In the field of mathematics education, ‘learning as objectification’ is important for assisting the learning of algebraic concepts (Daher and Musallam, 2018; Radford, 2004). In physics education, learning abstract concepts also presents a challenge due to the nature of physics concepts being both concrete and abstract. The abstract nature of physics concepts often requires idealisation through mathematical modelling (Maison et al., 2019), in this aspect, objectification is helpful.

However, the reliance on object-oriented representations may lead to misconceptions of abstract concepts. For instance, equating Energy with a physical object shown in this study may lead to misconceptions about its forms, transformations, and interactions in various scientific contexts. Such misconceptions can impede students' ability to apply abstract scientific concepts accurately and effectively in problem-solving scenarios. This research also revealed that participants possess similar misunderstandings regarding scientific concepts; they conceptualise Gravity, Buoyancy, and Energy as entities that can possess weight or temperature.

This means that the objectification process, on the one hand, integrating embodied experiences through objectification has been proven beneficial to science learning. In this research, it shows that this can construct students' understanding of abstract concepts. Yusof et al. (2022) also employed interviews to identify students' understanding of sound propagation, highlighting the importance of incorporating students' embodied experiences in shaping instructional strategies of abstract concepts. On the other hand, the above discussion shows it can lead to misconceptions. Therefore, it needs more attention as it has the potential to serve as a resource for enhancing science education but needs guidance for educators to achieve that.

5.2 Conceptual Understanding and Context

Based on the radical embodied cognition employed by this research, cognition is what occurs when the body interacts with the physical and cultural world, and it must be examined through the dynamic interplay between individuals and their environment. These contexts do not merely act as a backdrop for learning; rather, they form an integral part of the learning process itself.

In accordance with these arguments, this section will demonstrate the pivotal role of the sociocultural context in the conceptual understanding of scientific concepts by answering the second part of the main research question: *How are students' understandings of scientific concepts related to their embodied experiences and situated context?* Section 5.2.1 discusses three important contextual factors. Section 5.2.2 illustrates how context becomes a resource for conceptual understanding. Section 5.2.3 explains how context can also lead to misconceptions.

5.2.1 Family, School, and Online as Important Contexts for Conceptual Understanding

Building upon Vygotsky's situated learning theory, Lave and Wenger (1991) advocate for an understanding of learning as engagement in, as well as a facet of, social practice or ongoing activities in the real world. These activities invariably occur within specific contexts. This section will elucidate three context factors identified in this study as highly relevant to science education: school context, family context, and online context.

The first context factor to mention is the school context. This context has proven fundamental in shaping students’ comprehension of scientific concepts (Pallotta et al., 2022). In this study, many source domains used in the questionnaire responses are derived from scientific concepts known through school-based learning. Participants in interviews also emphasised the importance of school knowledge in providing resources to comprehend and construct conceptual understanding. This information primarily includes their classroom learning and highlights the importance of science instruction in schools for helping students build scientifically accurate concept knowledge. It also relates to the content of textbooks. From a cultural-historical theoretical framework perspective, textbooks can be considered cultural products with a significant cultural mission, exerting a formative influence on individual development and the cultural reproduction of society (Shi, 2021).

The second contextual factor is family. Existing literature has underscored the critical role of parental engagement in augmenting students’ learning outcomes in science. The family educational resources factor relevant to science learning includes students’ responses on the number of books owned, other supportive elements such as home background, and the highest level of their parents’ education (Mullis et al., 2020; Wiberg and Rolfsman, 2019). In this study, participants conveyed during interviews that a multitude of information was garnered from books read at home and conversations with family members, regardless of whether they were in Grade 3, Grade 4, or Grade 5. This suggests that the family and the family environment a crucial conduit through which students acquire information related to scientific concepts. Participants specifically mentioned that their individual conceptual understanding was also related to their parents' specialisms in Section 4.5.2. Davis-Kean (2005) also emphasised this point, explaining that education levels directly influence how parents transform home environments for learning and how they work with their children to promote academic achievement. This study's results further highlight the recent findings on the family context's impact on science concept learning, suggesting that parents should be cautious about the conceptions of learning science they portray in their words and deeds to help foster their children's deep learning motives and strategies (Zhou et al., 2022).

The third context factor is the online context. In the study, participants across all Grade groups mentioned how the internet provides source domains for metaphor construction and information contributing to their conceptual knowledge. These results demonstrate that the online context offers science learners opportunities to interact with content-specific messages. The effectiveness of meaning-making that occurs in such online spaces has been debated. Marsh (2018) argues that these spaces provide only social support, not scientific knowledge gain, as most science-specific social media content is designed to disseminate information rather than encourage dialogue (Lundgren et al., 2022). However, Russo (2012) emphasises that if people and institutions use social media to share and communicate about scientific practice, such spaces can be viewed as informal learning environments. In this study, even though students mentioned much information obtained through online platforms, its effectiveness should be evaluated critically. How this information influences students' understanding of scientific concepts will be discussed further.

5.2.2 Context May Also Assist the Descriptors for Expressing Conceptual Understanding

The results of this study also show that source domains may also assist in the description and comprehension of scientific concepts.

According to the initial articulation of the sociocultural theory of Vygotsky (1934), three types of source domains derived from culture-specific metaphors, Abstract Concept, Non-Physical Entity, and Language Character, can be perceived as symbols, which are acquired in a social context and serve as tools for both sharing meaning with others and constructing an individual's understanding of the world (Vallotton and Ayoub, 2010). This definition means that symbols are inevitably connected with sociocultural context. These forms of symbolic knowledge have strong purchases on life and learning, being intrinsically linked to culture and cultural practices such as art, myths, stories, and rituals (Habermas, 2001). In this study, while these three source domains are less prevalent, constituting 8.7% of the dataset, their influence is profound. Based on Langer’s classification (Langer, 1953), symbols can be categorised into two forms: discursive and presentational. Both forms are exemplified in this study.

The first category comprises discursive symbols. This traditional understanding of symbols adheres to established conventions that are unambiguous, such as numerical or scientific symbols, which are manipulated through specific rules. Moreover, language is fundamentally discursive, signifying that it consists of fixed units of meaning that amalgamate to form larger units capable of definition and translation (Langer, 1953). Two types of discursive symbols were employed as source domains in this study: abstract concepts and language characters.

Regarding abstract concepts in this research, as delineated in Section 4.2.2, these primarily constituted scientific concepts. Studies in science education have indicated that comprehension of established scientific knowledge can promote the learning of novel scientific concepts. Michel and Neumann (2016) explore the nature of science and its impact on the learning of scientific content, positing that an in-depth understanding of the nature of science can enhance the comprehension and integration of various scientific concepts. This aligns with the work of Lederman (1992), which examined students’ and teachers’ conceptions of the nature of science, unveiling that a robust understanding of the nature of science can influence the perception and integration of scientific concepts. This suggests that the scientific knowledge students have previously acquired can underpin further learning in science. In this study, the use of scientific concepts as source domains to describe other scientific concepts also substantiates this argument.

Language characters emerge as an important source domain for culture-specific metaphors in this study. The symbolic representation of language as cultural identity and the influence of complex scientific terminology on learning opportunities have been subjects of scholarly investigation (Brown and Ryoo, 2008). With an increasing number of students engaging with science education in a second language, the necessity for research to explore the effects of language on the understanding of scientific concepts becomes paramount (Salleh, 2006). The effective integration of linguistic components into science education is seen to foster understanding and conceptual development, especially in bilingual settings where language plays a crucial role in students' comprehension of scientific principles. The current research also notes that participants utilise lexicons from both English and Chinese to aid their conceptualisation of the term Magnet. This indicates that students acquire characters from more than one language through their sociocultural contexts, which can all serve as resources for scientific learning.

The second category of symbols is the presentational symbol, which, by definition, finds expression in rituals, myths, and art, aligning particularly well with portrayals of internal life that are both emotional and subjective (Reichling, 1993). Distinguished from discursive symbols, presentational symbols are open to interpretation and offer educators an alternative understanding that transcends the dominant logical role of symbolic representation (Langer, 1953). The potency of presentational symbolisation lies in its capacity to convey dynamic rather than static meanings. The primary attribute of these symbol systems is their creativity and openness. Each symbol may be interpreted and deconstructed based on individual sociocultural connections. Such systems might bear signifiers that resonate directly with an individual's real-life experiences or with the collectively understood meanings within a community. These symbols have the potential to evoke myths and rituals imbued with profound emotional undercurrents such as love, fear, or cultural identity (Gardner et al., 2013).

In this research, such symbols are primarily linked to Non-Physical Entities which serve as the source domain for culture-specific metaphors. In the realm of science education, this dimension has been scrutinised, particularly its confluence with domains such as religion, revealing that students often attempt to align their personal beliefs about God with their scientific understanding, which is grounded in evidence, proof, and experimentation (Torres et al., 2021). Notably, such expressions are also shown in this research even though China is not a religious state. Within this study, participants employed many symbols with religious connotations to describe scientific concepts, such as *God* and *Magic*.

Furthermore, the Non-Physical Entities utilised by students also included numerous fictional beings, like the Hulk and elves, which are characters in stories. Research has reported that drama enables students to feel involved and reflect on situations based on fictional contexts that would not otherwise be available to them (Wieringa et al., 2011). While these symbols lack a standardised and uniform definition, within the context of the study, students mapped the attributes they associated with these entities onto their conceptual understanding of scientific concepts, resulting in the generation of metaphors, which are employed for understanding scientific concepts. However, given the subjective nature of these presentational symbols, the interpretation of these symbols becomes particularly significant.

The aforementioned discussion corroborates that not only physical objects but also symbols developed from various contexts and resources can influence the learning of scientific concepts. This is consonant with the sociocultural perspective on learning, which posits that cultural tools, whether semiotic or material, play a critical role (Danish et al., 2020; Vygotsky and Cole, 1978). This concept argues that not only the aforementioned physical objects can elicit embodied experiences, but also non-embodied symbols mentioned in this section, can mediate what and how we think (Jakobsson and Davidsson, 2012). Particularly, these non-embodied symbols, which are relevant to sociocultural context, are believed can be used to help students do better in school and their social lives (Ladson-Billings, 2022). Its importance cannot be ignored.

5.2.3 Context Can Lead to Misconceptions

The above sections demonstrate how various contextual factors and the symbols they generate serve as resources for students' scientific concepts learning. However, these cultural tools can also exert a negative influence on their conceptual learning in science, leading to misconceptions.

The first point to consider is that sociocultural context-relevant symbols do not invariably facilitate the learning of scientific concepts but can also give rise to misconceptions in scientific understanding.

For Abstract Concepts, this study also reveals how employing scientific concepts as source domains may lead to misconceptions. Section 4.3.4 cites the example *Gravity is like Buoyancy, because it can make us fly*, illustrating the risks when complex scientific concepts are misunderstood or misapplied, potentially leading to an erroneous understanding of other concepts. Previous studies have stated that abstract concepts commonly are difficult, and an understanding of an abstract concept is more likely to need understanding from a number of other related concepts which leads to challenges (Fajriyanti and Sayekti, 2022). When one abstract concept is employed to elucidate another, the inherent complexity of the initial concept can lead to an amplification of potential misconceptions.

Regarding non-physical entities, although these resources are plentiful, the quality of the choice made is frequently questionable. In the study, the source domain employed by participants included entities such as monsters, clowns, and supernatural abilities. When these are related to scientific concepts, the examples do not demonstrate their utility in aiding conceptual understanding. Furthermore, the literature review calls into question the accuracy of online materials.

Moreover, an examination of these non-physical entities indicates an affective response towards the concepts. For example, source domains such as *god* and *magic* were frequently utilised, irrespective of the concrete or abstract nature of the concepts. This usage correlates with China’s distinctive sociocultural background, which exists in a deeply ingrained culture of superstition. There are ongoing efforts to integrate scientific understanding more broadly. Consequently, younger students encountering scientific concepts for the first time may interpret them through a prism of cultural superstitions and non-scientific beliefs. These metaphorical representations also highlight their unfamiliarity with the concepts, underscoring the discernible discrepancy between their current comprehension and standard scientific viewpoints. If such symbols continue to be widely employed, the learning of scientific language could be adversely affected.

Beyond the influence of symbols, the application of the sociocultural context to science education also presents challenges. As discussed in the previous section, except for school context, both family and internet contexts can provide resources for scientific concepts as informal education approaches. Merging these informal educational settings can enhance students' awareness and understanding of science (Soh and Meerah, 2013), and offer more student-centred and participatory learning experiences (Czerkawski, 2016). However, research also suggests that informal science education may sometimes be deficient in the structured guidance and assessment mechanisms that characterise formal educational settings, potentially resulting in inconsistencies in the quality and accuracy of the information conveyed. It is crucial to recognise that while these informal education contexts can positively impact the learning of scientific concepts, potential negative effects associated with informal learning environments also exist.

In this study, students from the third to fifth grade reported how their understanding of concepts was shaped by information provided by their families. Such information from informal science learning activities may not consistently align with formal curriculum standards, which can lead to confusion or conflicting information for students. Moreover, the fifth-grade participants have begun to recognise that the information provided by different families may vary. Accessibility to informal science education opportunities can differ based on socioeconomic status, geographic location, or cultural background, potentially leading to disparities in educational outcomes. This necessitates a critical perspective on information acquired outside of formal schooling.

Moreover, except for its role as a resource for comprehension and articulation, as discussed in Section 5.1.2, language can also pose difficulties in understanding scientific concepts. The primary issue is the divergence in the meaning of scientific concepts between everyday and scientific contexts.

Indeed, even within Western cultures, both educators and learners acknowledge difficulties not only in grasping concepts but also in employing scientific language and discipline-specific terminology (Wang et al., 2007). Research in this area suggests that children can hold multiple meanings of content and practices as they navigate their everyday lives. Some terms do seem to have similar meanings in everyday and scientific contexts, such as the use of evidence, while other practices can have different meanings, such as students' viewing arguments as yelling or fighting (Bricker and Bell, 2008). This issue assumes greater significance in the Chinese context, where scientific learning occurs through a distinctive language. Chinese science education is distinct owing to cultural divergences from Western paradigms. The unique characteristics of the Chinese language and the translation of scientific concepts amplify the linguistic challenges. The convergence of these two factors—native language intricacies and translation nuances—sometimes leads to a disparity between the scientific and everyday meanings of concepts, a phenomenon that is evident in this study.

In the Chinese language, the scientific concept of Force is translated as 力, which means power or strength in the everyday context. This meaning diverges from its scientific definition, which describes the interaction between two bodies. Instead, it aligns more closely with the idea of Energy, thereby leading to students' confusion about these two concepts. The conflation of these two concepts has long been one of the significant misconceptions in Chinese science education (Gao, 1998). In this study, many source domains of the concept *Energy* were related to various kinds of force, such as Gravity, friction, and Buoyancy. Moreover, in the questionnaire, participants also provided expressions like *Gravity is like earth, because earth has Gravity* and *Gravity is like water, because water has Gravity*. While these metaphors were categorised as invalid metaphors, they reveal students' understanding to perceive force as a property of an object rather than the interaction between two entities.

5.3 Relationship between Embodied Experiences and Context for Conceptual Understanding of Scientific Concepts

This section will discuss the relationship between embodied experience and context, both of which are crucial factors for conceptual understanding. Through analysis, two main relationships have been identified. First, the occurrence and comprehension of embodied experience are inseparable from context. Second, both can serve as significant resources for conceptual understanding, acting as cultural tools that mediate conceptual understanding. These points are discussed in sections 5.3.1 and 5.3.2, respectively.

5.3.1 Embodied Experience Needs to Be Understood Within Context

According to the situated learning theory, learning should not be described as a simple process of transferring information, but the process of adopting and utilising material resources that form a part of the shared repertoire of a community of practice, which encompasses domain-specific instruments, problem-solving methodologies, language, symbols, and processes (Wenger, 1998). Hence, the appropriation of material resources is not detached from context but is rather entrenched within a sociocultural matrix. This study shows that embodied experiences are important resources for conceptual understanding, their interpretation cannot be understood in isolation from their context.

As demonstrated by participants in their interviews, particularly when discussing their responses to the first theme, the use of personal experiences to generate metaphors, they inevitably referenced the environment in which such embodied experiences occurred. The students mentioned that these experiences took place in various settings, such as the family or school context. Some students also noted that different contexts lead to different experiences, thereby influencing conceptual understanding. This indicates that the comprehension of these embodied experiences must be contextualised and not viewed as context-free. This aligns with the arguments of radical embodied cognition, which similarly emphasise the understanding of human activity within situated environments. Therefore, as researchers and educators, we must better contextualise children’s scientific thinking processes as they unfold in their daily lives—with their peers, families, and cultural communities (McWayne and Melzi, 2023).

5.3.2 Both Embodied Experience and Context Are Crucial for Conceptual Understanding

The above discussion demonstrates that both embodied experiences (Section 5.1) and the contexts in which students are situated (Section 5.2) are crucial resources for their understanding of scientific concepts. Embodied experiences that happen in various contexts can form the foundation for students’ comprehension and expression of scientific concepts. While context can also enable students to manage tasks and engage competently in activities that would otherwise be unattainable without these resources (Mercer, 2019) through their embedded symbols. This means that they are all vital resources for students’ conceptual learning in science.

The previous section referenced the role of symbols as a cultural tool in students' learning of scientific concepts. The essence of cultural tools encompasses both physical and mental actions, framed as an "agent acting with mediational means" (Wertsch, 1998, p. 155). It extends beyond symbols to include students' activities. This corresponds with the role of embodied experiences and context in conceptual understanding. Whether symbols are inherently related to the sociocultural context or embodied experiences they must be rendered relevant and meaningful by interlocutors in the context of specific tasks (Furberg, 2016), as they all serve as cultural tools that mediate students' understanding of science concept learning. This study demonstrates that both approaches are crucial.

5.4 Metaphor Type for Scientific Concepts

This section focuses on the first sub research question: *What types of metaphors, universal or culture-specific, do students employ for scientific concepts* and the second question: *Is there a correlation between the types of metaphors and students' understanding of scientific concepts, and if so, how they are related?*

Sections 5.4.1 and 5.4.2 address these two questions respectively, while Section 5.4.3 explores the utilisation of metaphors in science education based on these inquiries.

5.4.1 Two Main Metaphor Types for Scientific Concepts

This section discusses the nature of students’ use of metaphors in understanding scientific concepts. The main relevant results are that most of the primary school students in the study were able to create metaphors, containing both universal and culture-specific metaphors. The distribution of these two metaphors differed in terms of grade level.

The analysis results from the first step of coding, as presented in Section 4.1, show that, of the questionnaire responses collected, over two-thirds were categorised as valid metaphors. This indicates that primary school students have the cognitive ability to create metaphors. Among these metaphors, in this study, Universal Metaphor, which source domain is based on embodied experiences, constituted the majority of the metaphors used to describe scientific concepts, regardless of whether the participants were in their third, fourth, or fifth grade. Even for the selected concepts with the lowest representation, nearly 80% employed Universal Metaphor. Whilst the majority of metaphors used were Universal, Culture-specific Metaphors comprised a smaller yet notable portion, accounting for 8.7% of the total in this research.

These results cast light on the applicability of Conceptual Metaphor Theory. Many metaphors discerned in this study were Universal Metaphor, originating from embodied experiences. This is congruent with the central assertion of CMT, which suggests that our cognitive processes frequently depend on tangible experiences to grasp abstract concepts (Lakoff and Johnson, 1980c). In this investigation, although the scientific concepts examined were abstract, students consistently utilised concrete source domains like physical objects, humans, and animals for comprehension, thereby substantiating the claims of CMT.

Furthermore, the findings reveal that the source domains employed by participants are not limited to direct embodied experiences; indeed, they suggest that a series of entities that do not afford direct embodied experiences can also serve as source domains for abstract concepts. This sheds light on the intricate interaction between embodiment, context, and metaphor, a topic that continues to provoke debate within the field of cognitive linguistics. The current study challenges the cultural filtering perspective, which views culture as a sieve through which universal human experiences are modulated by sociocultural specifics to craft metaphorical expressions (Glucksberg et al., 2001). The data illustrate that context does not simply channel embodied experience but also independently contributes to the generation of metaphors. This shows the importance of context in the process of metaphor production.

From a sociocultural standpoint, learning is positioned and realised within dialogic meaning-making processes where learners engage in specific activities (Wertsch and Toma, 2012). Discussion in this section further supports this point by stressing that symbols, not directly linked to embodied experiences, can be valuable external sources used for metaphor creation. According to participants' responses in interviews, these symbols arise from various contexts, including schools, homes, and external reading. A deficiency of such resources can complicate the creation of metaphors, therefore require more attention from educators.

The distribution of these two metaphors varies across grades. Contrary to the prevalence of Universal Metaphors across all grade levels and selected concepts, the occurrence of Culture-specific Metaphors is variable. An ascending trend is observed from Grade 3 to Grade 5, with instances in Grade 5 being double those in Grade 3. This aligns with the principles of situated learning, which posits that learning involves a progression from the periphery to full participation within a community of practice (Lave and Wenger, 1991). An increase in students' use of culture-specific metaphors from grades three to five reflects their growing engagement with sociocultural contexts and the corresponding accumulation of experience.

This corresponds with empirical findings in the field of science education, which suggest that as students advance through different age groups, their cognitive development and capacity to grasp sociocultural context symbols tend to progress. Older students may derive greater benefit from cultural materials that link scientific knowledge with societal and ethical issues, thereby cultivating a more profound understanding of the societal relevance of science (Parsons and Carlone, 2013).

5.4.2 Both Metaphor Types Can Represent All Levels of Conceptual Understanding

According to the theoretical framework in this research presented in Section 2.6.5, this study categorised students' conceptual understanding into three groups: Intrinsic Property, Extrinsic Property, and Misconception. The previous section mentioned that both types of metaphors identified in this study can be used to describe these three different conceptual understandings.

In Section 4.4, the examples illustrate that both universal and culture-specific metaphors can be employed to describe various types of conceptual understanding. This demonstrates metaphor as a crucial instrument for articulating students' scientific cognition, and further substantiates the connection between metaphors and scientific cognition. Metaphors are instrumental not only in everyday thought but also in the grasp of scientific subjects (Niebert et al., 2012). This further highlights that various types of metaphors in this study can describe different levels of conceptual understanding.

As pivotal means for articulating scientific concepts, both types of metaphors have been demonstrated to facilitate the necessary scaffolding for conceptual understanding within the study, since they possess attributes sufficient to convey key learning concepts. However, owing to differing bases of origin, universal and culture-specific metaphors exhibit considerable variation. As discussed in Section 5.2.1, culture-specific metaphors incorporate numerous presentational symbols, such as non-physical entities, the comprehension of which is entirely subjective. These metaphors afford each learner the flexibility to identify with and connect to shared meanings. Utilising this type of rich and local linguistic resources for learning, including metaphors, signs, and symbols, enables students to establish connections between self and text, fostering self-awareness and responsibility for their own learning (Crick and Grushka, 2009).

5.4.3 Universal Metaphors are More Connected with Misconception

The chi-square correlation test presented in Section 4.4.1 shows a link between conceptual understanding and metaphor usage by participants. This indicates that, in addition to both types of metaphors explaining conceptual understanding, there is a special connection between them. The most notable link revealed by this study is that misconceptions are more inclined towards the use of universal metaphors, more so than culture-specific metaphors.

This phenomenon is particularly pronounced in Grade 5 students. As previously mentioned, the proportion of culture-specific metaphors used by Grade 5 students is higher than that in Grades 3 and 4. The data presented in Section 4.3.3 indicate that these frequently employed culture-specific metaphors are utilised to describe intrinsic and extrinsic properties, rather than misconceptions. Misconceptions among Grade 5 participants are predominantly depicted using universal metaphors.

This may stem from the widespread nature of embodied experiences that lead to misconceptions arising from a superficial understanding of these experiences. Empirical evidence suggests that misleading or inaccurate embodied metaphors can culminate in the development of flawed mental models of scientific phenomena (Anderson, 2018). Section 5.1.3 also illustrates how numerous misconceptions can originate from embodied experiences. While the import of embodiment in scientific learning is recognised, it necessitates a more scrupulous critique. These findings inform us of the necessity to consider how universal metaphors, based on embodied experience, should be utilised for scientific concepts.

In science education, the extended use of scientific metaphors is considered a double-edged sword: while they can foster understanding or misunderstanding of scientific concepts, they may also lead to the development of either accurate or inaccurate knowledge regarding scientific phenomena (Cameron, 2003). Studies indicate that students may not always decode instructional metaphors as intended, which can result in misconceptions (Niebert et al., 2012). This may be linked to the lack of appropriate metaphor types being utilised in instruction. The discussion in this section has revealed that Universal Metaphors need to be paid more attention to since they can tend to connect with misconceptions. Educators can draw on this information to make informed choices regarding metaphor use in science instruction.

5.4.4 Concrete and Abstract Concepts Have Different Metaphor Type

The special relationship between metaphor type and conceptual understanding is also evident in the use of different metaphor types for concrete and abstract concepts.

In this study, no Universal Metaphors were used to describe the extrinsic properties of the concepts of Gravity and Buoyancy in the study. This is because the characteristics of extrinsic properties are typically contingent upon the relevant environment. However, for these highly abstract concepts, there are fewer daily environmental occurrences. Hence, there is an absence of associated extrinsic properties. Moreover, in the interviews, none of the participants mentioned how they utilised the first theme, physical experiences, to describe and understand abstract concepts.

These findings underscore the differential impact of embodied experiences and sociocultural contexts on concrete and abstract concepts. Concrete concepts are typically more closely associated with sensorimotor experiences, which facilitates their comprehension and connection to physical actions or experiences (Maschio et al., 2021). Conversely, abstract concepts are frequently acquired through linguistic information and internal experiences; this reliance on linguistic information for abstract concepts contrasts with the sensorimotor grounding of concrete concepts (Borghi, 2022). This elucidates why, in the context of science education, abstract concepts are consistently deemed more challenging relative to concrete concepts. Understanding abstract scientific concepts typically necessitates that students grasp intricate and intangible ideas that are not readily observable or directly linked to their embodied experiences. The difficulties students face with this are also reflected in the study. The proportion of intrinsic properties associated with all abstract concepts identified in the research was significantly lower than the average, while misconceptions were substantially higher.

This further highlights the necessity of embodied experiences in the construction of conceptual understanding. Such divergent approaches to constructing understandings of concrete and abstract concepts result in distinct metaphor usage, warranting the attention of educators.

5.5 Summary

This section will summarise the main findings presented in this chapter from the study. The utilisation of a mixed-methods approach, which included a metaphor questionnaire and follow-up interviews, resulted in several key findings.

Focusing on the first part of the main research question, *'How are students' understandings of scientific concepts related to their embodied experiences?'*, the study's outcome is as follows: Embodied experience is frequently employed for constructing and expressing conceptual understanding. The process predominantly involves embodied experiences stemming from students' interaction with accessible objects and hands-on activities. However, embodied experiences may also give rise to misconceptions, notably in the objectification of scientific concepts and the misleading aspects of everyday embodied experiences.

In addressing the second part of the main research question, *'How are students' understandings of scientific concepts related to their sociocultural context?'*, this study yielded three main findings. Conceptual understanding of scientific concepts is primarily associated with family, school, and internet contexts. These contexts contain numerous symbols that can serve as expressions of conceptual understanding. However, these contexts may also give rise to misconceptions.

Regarding the main research question, the study also found that embodied experience and context are relevant to constructing conceptual understandings of scientific concepts. Embodied experiences need to be understood within their specific contexts. Additionally, both can serve as cultural tools, becoming significant resources for conceptual understanding.

As for the study's first sub-question, *'What types of metaphors, universal or culture-specific, do students employ for scientific concepts?'*, the findings indicate that the majority of metaphors used by students are Universal Metaphors based on embodied experiences. The proportion of Culture-specific Metaphors is smaller but not negligible. Concerning the second sub-question, *'Is there a correlation between the types of metaphors and students' understanding of scientific concepts?'*, the study shows that both types of metaphors can be used to describe various levels of conceptual understanding. Additionally, Universal Metaphors are more often associated with misconceptions. Furthermore, the types of metaphors used for concrete and abstract concepts differ due to their varying relationships with embodied experiences.

Through these discussions, the study has illuminated the relationship between embodied experience, sociocultural context, and metaphor, as well as their influence within the domain of science education.

6 CONCLUSIONS

6.1 Overview of the Study

As mentioned in Section 1.2, there have been a considerable number of science education studies which have employed embodied cognition to promote students' conceptualisations of scientific concepts. However, very few studies have focussed on how the daily embodied experiences impact students' understanding and how the embodied approach can be combined with students' situated context.

In light of this, the present study adopted an exploratory stance, exploring Chinese students' conceptualisations of eight selected scientific concepts, by means of analysing metaphors they created in the 'X is Y' form. The study employed a version of Conceptual Metaphor Theory (Lakoff and Johnson, 1980c), whereby metaphor is seen as both a cognitive tool for conceptualisation and as a social phenomenon (Littlemore, 2015), with language as one of several means of expressing it. Metaphors can accordingly act as a mediational tool for investigating conceptual understanding. In this study, by examining individual participants' metaphors in the questionnaires, the hope was that the results could not only shed light on how participants understood these scientific concepts but also identify how these understandings were related to their embodied experiences and context, as well as how they lead to students' misconceptions of scientific concepts.

Additionally, very few studies have argued for the specific investigation of how students use metaphors to explain scientific concepts, and how it links with different experiences and sociocultural backgrounds. Through analysing the metaphors participants used in this research, the present study also intended to explore how different types of metaphors are linked with different types of conceptual understanding.

Methodologically, the study examined the validity of using a questionnaire for eliciting metaphor tasks, investigated the difficulty of analysing these metaphors and offered possible solutions, by introducing the method for analysis and relevant results. The present study adopted the mixed method approach involving two phases: metaphor questionnaire investigation and follow-up interview with participants. The use of mixed methods research not only shows the patterns of students' metaphor use but also detailed how the relationship between metaphor use and conceptual understanding. A content analysis approach was used for analysing metaphors in the questionnaire and a thematic analysis approach was employed for analysing interview data.

The main findings of this research elucidated that students' conceptual understanding of scientific notions is fundamentally rooted in their embodied experiences through tangible interactions and accessible activities, yet these experiences also have the potential to lead to misconceptions and objectification of scientific concepts. The study further expounded on the interplay between students’ sociocultural context and conceptual understanding, highlighting the role of symbols and the influence of context on embodied experiences.

Moreover, the analysis revealed a predominance of universal metaphors with a smaller percentage of culture-specific metaphors. A notable correlation was observed between metaphor types and the understanding of scientific concepts, where culture-specific metaphors align with intrinsic and extrinsic properties, and universal metaphors often signal misconceptions.

6.2 Significance and Contributions of the Study

The current study represented an original and exploratory empirical contribution to the embodied science education field by examining how metaphor can act as a mediational tool, whereby Chinese primary students interpreted scientific concepts via their metaphorical expression.

Firstly, this study was intended as a contribution to the current dearth of research on embodied science education. Numerous studies in the last two decades have investigated embodied cognition and how it can be employed in science education. However, there is a shortage of empirical studies, which investigate the interplay between embodied experiences, context, and how it impacts students’ conceptualisations. Moreover, the theory in the cognitive linguistics field including conceptual metaphor theory, offers a connection between metaphor, embodied experiences and context and, therefore could be a valuable tool for investigation in this field. In the present study, the research design and methods that use metaphor as an investigation tool managed to generate critical thought and discussion about how students' understanding developed through their embodied experiences and situated context, as well as how it impacts students' conceptualisation of scientific concepts.

Moreover, as discussed in Chapter 3, there are few details in the literature concerning how to resolve the methodological problems with this sort of metaphor elicitation technique. Davis (2009) remains one of the few studies that attempts to supply participants with examples of metaphors. Unlike the metaphor-analysis studies discussed earlier, the present study not only collected information on task problems but also offered some preliminary considerations of training issues, helping participants establish a working definition of metaphor and clarifying the value of metaphor creation. The results strongly suggested that the explicit metaphor approach can be used as a valid means of uncovering participants' conceptualisation.

6.3 Implications and Applications of the Study

This section discusses the application and impact of the study’s findings. It explores how the conclusions drawn from this research can be applied in educational practices and policies to enhance the effectiveness of science education.

6.3.1 Expanding Methods for Using Embodied Experience in Science Education

This study’s exploration and discussion regarding embodied experience suggested that there are more possibilities for its use in science education. The findings highlight two main aspects where new perspectives for integrating embodied experience can be effectively applied.

First, Section 1.2 mentioned that currently there is no consensus on how to understand the role of the body when it is used in the science education field (Kirsting, 2023). In this study students drew on their everyday embodied experiences, particularly those involving interactions with accessible objects for their understanding and expression of scientific concepts. Following this argument, educators can integrate more everyday embodied experiences when teaching scientific concepts, offering increased instructional possibilities for linking the learning of scientific concepts to everyday contexts. By grounding complex scientific ideas in familiar scenarios from daily life, students can better relate to and understand these concepts (Kervinen et al., 2020). At the same time, education policymakers and curriculum developers should promote the inclusion of embodied learning in science education standards and encourage schools to create more real-world learning opportunities to enrich students’ diverse embodied experiences. Teacher training programs could also include content on how to identify and utilise students’ everyday embodied experiences, equipping teachers with methods and techniques for integrating these experiences into science teaching. By equipping teachers with the necessary skills and knowledge, professional development initiatives can enhance their capacity to effectively link scientific and everyday concepts in their teaching practices (Aiyedun and Jacob, 2021).

Second, the discussion in Section 5.3 highlighted the relationship between embodied experience and context, suggesting the utilisation of specific embodied experiences within the local context. This indicates that many embodied experiences unique to the local context can be applied. For example, in the context of this study in Weihai, students’ everyday experiences related to the ocean and fishing may be unique and valuable embodied resources. Indeed, many students referred to the ocean as the source domain when responding to the questionnaire. Teachers could design science activities related to these local experiences, enabling students to apply and understand scientific concepts in familiar contexts. This place-based education, which builds on familiar contexts for students and educators, connects science to other disciplines, provides local relevance to global issues, and enhances learning experiences (Smits et al., 2020). Future research should continue to explore the impact of embodied experiences on science learning in different contexts, particularly cross-cultural comparative studies, to further validate and expand the findings of this study.

In summary, expanding the use of embodied experiences in science education could provide more potential for improving the quality of science education and students' learning outcomes.

6.3.2 Importance of Local Context in Chinese Science Education

This study demonstrated that family, school, and online contexts are three types of contexts that mainly influence students' understanding of scientific concepts. Each of these contexts reflects the importance of the local context in science education.

First, the role of the family context in this study was characterised by interactions and information transmission among family members, which is deeply rooted in specific cultural and social backgrounds. The cultural background, values, and lifestyle of each family influence students' interest and understanding of science. For instance, whether science discussions are valued within the family and whether parents possess scientific knowledge depend on the economic, cultural, and educational levels of the local context (Wang and Wildman, 1995). Thus, the family context significantly reflects the support and influence of the local context on students' science learning.

Second, for the school context, research emphasises that science teaching in school science teaching contexts is influenced by local factors such as education policy and community dynamics (Marco-Bujosa et al., 2020). This is also reflected in this study, which suggests that many metaphors students used in the questionnaire are based on the scientific concepts learned in school. These shows that the local context can also impact science learning through influencing school science teaching.

Third, although online learning resources are globalised, students’ access to and use of these resources are limited by the local context. The sample school of this study is located in the eastern coastal regions in China, and participants from Grade 3 to Grade 5 in this study mentioned their utilise of online resources. However, research in China has highlighted that regions with higher economic development tend to have better internet access, particularly in economically advanced areas like the eastern coastal regions (Jiang et al., 2022). Therefore, it is necessary to be noticed the effective use of the online context still relies on the support and security provided by the local context.

By analysing the impact of these three contexts on students’ conceptual understanding and its relationship with situated local context, it shows that each context does not exist in isolation but is deeply influenced by local culture, economy, policies, and other factors. By integrating family, school, and online contexts as a whole, it might provide a new perspective for addressing the challenges currently faced in Chinese science education. Section 2.2 mentioned the differences between Chinese science education and that of Western countries, noting that the traditional lecture-based and teacher-centred teaching methods limit the development of science education. Regarding this issue, the family context can serve as a supplement to the school teaching, enhancing students' interest and extending the effects of classroom learning. This kind of supplement has been proven to exist in the Chinese education system, influencing students' choices of subjects in university (Sheng, 2017). The online context could provide abundant learning resources and interactive platforms, enabling students to engage in self-directed learning and collaborate through online platforms, enhancing the enjoyment and effectiveness of learning. By learning within various contexts and engaging deeply with their situated local context, it is possible to overcome the limitations of traditional Chinese teaching methods.

In summary, integrating the three types of contexts identified in this study and deeply engaging with the local context might effectively address the limitations of traditional Chinese teaching methods. This approach could not only enhance conceptual understanding but also create a more dynamic and relevant learning environment for students. To practically and realistically address these changes, educators need to consider specific strategies such as incorporating local cultural elements into the curriculum, adopting interactive teaching methods, and providing continuous professional development for teachers. By doing so, the theoretical benefits of these approaches can be translated into tangible improvements in the classroom.

6.3.3 Misconceptions as Resources for Conceptual Understanding

Many distinct science education research traditions emphasise different aspects of bridging students’ experiences from their everyday lives and school science. One tradition involves research associated with conceptual change studies grounded in cognitive and constructivist learning perspectives. A central focus has been on so-called misconceptions held to be rooted in students’ everyday experiences and some have argued that these misconceptions are obstacles to students’ development of conceptual understandings (Vosniadou et al., 2008). In this area, many published peer-reviewed articles refer to misconceptions as obstacles to learning. In science education research that takes this view, misconceptions hinder learning by preventing access to central scientific ideas, blocking the ability of the student to understand concepts, and affecting how students acquire new knowledge (Larkin, 2012). This is parallel with King (2010) who unveiled that misinterpretations found in the textbook of ‘Earth Science’ influenced students’ understanding of a scientific text making it difficult to comprehend further information or knowledge as a reader.

Other researchers within the same research tradition have argued that students’ intuitive ideas might be beneficial for school science learning (Campbell et al., 2019). Instead of focusing on students’ misconceptions or science difficulties, there are also researchers who argue that student resources—their preconceptions and ideas about science—that might be intuitive and raw but remain the basis upon which scientific knowledge can be built (Luna, 2018).

In this research, the Misconception category pertains to the inaccurate articulation of selected concepts by participants. However, research findings also indicate that misconceptions in scientific concepts extend beyond this category and also encompass the Extrinsic Property category. This suggests that even though such understandings might have the potential to evolve into misconceptions, they can still act as foundations for correct scientific knowledge, similar to the view presented above that misconceptions could serve as valuable resources to construct correct knowledge rather than a barrier to be amended. However, in this study, it is shown that these misconceptions are more often associated with universal metaphors. This highlights the need for particular caution when using universal metaphors in science teaching.

First, this requires teachers to have a deeper understanding of content knowledge. Studies have shown that teachers with a strong grasp of the content are better equipped to identify and address misconceptions in their students (Lewis et al., 2021; Sadler et al., 2013). This becomes particularly important in metaphor-based teaching, as it may contain additional misconceptions. Teachers with richer content knowledge could select and adopt a wider variety of universal metaphors for instruction, thereby reducing the likelihood of misconceptions being generated by metaphors. This also requires for more emphasis on teacher training programs.

At the same time, it is essential to create a classroom environment that encourages open dialogue about misconceptions. Teachers should foster a culture where students feel comfortable expressing their misunderstandings without fear of judgment (Maskiewicz & Lineback, 2013; Desstya et al., 2019). This approach can aid in identifying misconceptions. Furthermore, these classroom dialogue could also further explore why students used particular metaphors, which can then be used to address misconceptions in subsequent teaching activities.

Previous discussions indicated that both embodiment and context can influence students’ conceptual understanding. Factors contributing to misunderstandings should include various factors such as textbooks, teaching methods, environmental influences, language barriers, and pre-existing beliefs (Masfuah et al., 2021). However, in this area, despite the large body of literature on the area of school student misconceptions from around the world, there has been relatively little cross-cultural research to directly compare the prevalence of common scientific misconceptions amongst students from different cultural backgrounds. Indeed, whilst previous research does suggest the international nature of many misconceptions (Osborne et al., 1983), there is little evidence as to whether the prevalence of such common misconceptions varies from culture to culture.

This is important for the Chinese context because of its distinct science education background. It has shown that there is a large difference in the prevalence of misconceptions in the areas of physics tested between English and Chinese undergraduate students studying nonscience subjects respectively (Abrahams et al., 2015). This indicates that a universal approach to rectifying misconceptions across all cultural contexts might not exist. Customised investigations into effective techniques for conceptual change are crucial, considering the distinct cultural backgrounds involved. This research has presented several aspects of embodied experience and context that can lead to misconception in Chinese context, which can be used for educators to use in their teaching. Adopting the stance that misconceptions are resources, these factors represent valuable assets for the construction of scientific concept understanding.

6.3.4 The Use of Both Universal and Culture-Specific Metaphors in Expressing Scientific Concepts

In this thesis, Chapter 5.4 examined the relationship between metaphor and the learning of scientific concepts. It revealed that students utilise metaphors in two distinct forms: Universal Metaphor and Culture-Specific Metaphor. These two types of metaphors are all important for science education.

The first category, universal metaphors, are based on common embodied experiences arising from interaction with the physical environment (Kövecses, 2005) and align closely with the nature of scientific concepts. This is because they are also argued to be rooted in empirical evidence, logical reasoning, and the scientific method, which seek to elucidate truths about the natural world (Dobson et al., 1997). Furthermore, it was shown in this research that this type of metaphor is most frequently employed by students. In this way, one of the primary benefits of using universal metaphors in science education is their ability to make abstract concepts more accessible. Negrea-Busuioc et al. (2022) emphasize that visualization, when combined with metaphorical language, greatly enhances young learners' understanding of abstract scientific concepts. This perspective aligns with Niebert et al. (2012), who highlight that metaphors and analogies can incorporate experiential learning, making scientific concepts more relatable and easier to grasp. By integrating embodied experiences, universal metaphors offer a more concrete framework for understanding abstract scientific ideas. This research further indicates that students often face additional challenges in comprehending abstract concepts, suggesting that employing universal metaphors in explanations and instruction may effectively address this issue.

While some metaphors may have universal aspects, variations can still exist both interculturally and intraculturally (Kövecses, 2005). This study illustrated these variances, indicating that Culture-Specific Metaphors cannot be disregarded. While culture-specific metaphors are less frequently used in this research, this does not imply that cultural perspectives are unimportant in science education. In fact, education, including science, can benefit from integrating greater cultural diversity to foster students' deeper understanding and critical thinking regarding scientific concepts. It offers several advantages that universal metaphors cannot replace. Relevant research has shown that a culturally responsive pedagogy can enhance science education (Mansour, 2011). Especially for classes with diverse cultural backgrounds, educators can enhance the relevance and engagement of their teaching content by integrating culture-specific metaphors relevant to students' sociocultural context.

It is also important to provide students with appropriate teaching materials aligning with students' cognitive development stages since it could promote analytical thinking skills and enhance their understanding of the world around them (Wade et al., 2023). In this research, it shows that the use of metaphors could vary with different grade levels. The study indicated that as students progress through their grades, the number of culture-specific metaphors they use increases. Moreover, Grade 3 students expressed in interviews a deficiency in the richness of symbols. This might suggest that universal metaphors should be employed more at lower grade levels, while the use of culture-specific metaphors can be expanded as students age.

Moreover, Culture-specific metaphors can address the resistance to embodiment experienced by teachers and students as described previously. Instructors might resist methods and views that contest their initial professional socialisation or personal social presuppositions (Nguyen and Larson, 2015). By incorporating culture-specific metaphors with which educators are acquainted, embodied science education may overcome these challenges.

The above discussion in this research contended that both universal and culture-specific metaphors offer opportunities to facilitate science learning. Weade and Ernst (1990) observed that metaphors provide the opportunity to explain only part of the determined phenomenon. This implies that a single concept could be elucidated through multiple metaphors, each representing different aspects of its properties. To assist students in developing a robust and diverse conceptual understanding, educators need to find a balance between the use of universal metaphors and culture-specific metaphors. Through this approach, we can maintain the effectiveness of conceptual teaching while also respecting and utilising the cultural diversity of the students.

6.3.5 Research Implications

With reference to the metaphor studies on investigating participants' understanding, firstly, a considerable number of metaphor studies in the last two decades have examined both teachers' and students' understandings of teaching and/or learning; however, very few have examined participants' conceptual understanding of scientific concepts, such as Magnet/Gravity (Villamil and de Guerrero, 2005). Whether and how far participants can use metaphor to conceptualise their own understanding of scientific concepts and in what ways their metaphors of scientific concepts can be utilised for understanding their own conceptual understanding thus remains unclear.

In addition, the majority of metaphor studies have often been set up in one format, collecting, categorising, interpreting and reporting on metaphors from participants, rather than letting the participants have the opportunities to share their metaphors or to learn from each other (Hart, 2009). It seems unclear (a) what will happen, when participants enter into a discussion about individuals' personal metaphors and (b) in what ways the metaphor-based interaction can influence individuals' actual practices (e.g., their writing output).

Lastly, regarding the validity of the use of metaphor as a research tool, the last decade has, as noted above, seen a considerable number of studies employing a metaphor elicitation technique, involving an X is (like) Y format to investigate language teachers' and learners' understandings of teaching and/or learning. Although a few recent studies have reported the proportion of unsuccessful answers to this type of task, and identified a number of issues relating to task difficulty, in general, it remains the case that very few published metaphorical conceptualisation papers discuss in any real detail or depth the validity of the method used; indeed, a considerable number do not discuss methodological problems at all. What is needed therefore is an understanding of where and why the problems occur, plus an investigation of possible solutions. In sum, the research findings again supported the suggestion noted by other researchers (Jin and Cortazzi, 2011) that the “because” part, especially when accompanied by follow-up interviews can improve the validation of the researchers’ interpretations of participants’ metaphors. This can shed light on future research in this area.

6.4 Limitations

Although the present study has yielded findings that have both practical and pedagogical implications, its design is not without limitations.

The first limitation concerns the sampling. In the study, all participants were recruited on a strictly volunteer basis; it is thus not possible to view this sample as a representative sampling of the primary school students in China. For example, students who were not comfortable with talking about their scientific understanding may not be willing to participate.

Secondly, due to the volunteer principle, participants in this study didn’t consider the gender balance. Therefore, the findings might not apply to all students. There is also a problem related to data gathering, which derives from the fact that the current study is based on questionnaires and interviews, but without data related to students’ daily use of metaphor.

Thirdly, one potential limitation of this study lies in its focus on a single public primary school in Weihai, Shandong Province, which may restrict the generalisability of the findings. The specific socioeconomic and cultural context of the school means that the experiences of the participants and their families may not fully represent those of other regions or demographic groups. Additionally, the importance of utilising local or indigenous experiences in understanding and applying embodied teaching and learning highlights the need for caution when extrapolating the results to different educational settings.

In addition, data collection was completed at the end of the participants' daily classes, leaving no opportunity for further investigation when they were eager to return home. To better establish the extent to which embodiment and context can be used to support metaphors as pedagogical instruments, it would be useful to consider conducting intervention designs and further investigation.

6.5 Suggestions for Future Research

This study demonstrated the value of the use of metaphor-based activities in metaphor investigation in the field of science education, as well as how it can be connected with embodied experiences and context. It also leaves much room for future study in applied linguistic or educational research.

The results from the first step of coding, as presented in Section 4.1, showed that, of the questionnaire responses collected, over two-thirds were categorised as Metaphors. This indicates that even primary school students have a grasp of metaphors. Metaphors can be utilised as a tool to probe the thoughts of students, especially young learners. Furthermore, the ability to use metaphors was present in every grade level, with a notable proficiency in Grade 3, suggesting that students acquire this skill at a young age. This demonstrates that conceptual metaphors are not unfamiliar to students and highlights the role of metaphors in our cognitive processes. In turn, it becomes possible to draw conclusions on the genesis of students' conceptions about abstract scientific phenomena (Gropengießer, 1998). By using the CMT as an analytical approach, interview transcripts can be analysed from a language point of view and thus can help to answer questions about the conceptions' source domain and the underlying image schemata, as well as conceptual metaphors.

A possible area for future exploration is the interaction between and development of metaphors used between teachers and students in the science education context. It would be interesting to investigate what effects the discussion-based metaphor activities have on both students' and teachers' views of scientific concepts, and whether and how far metaphors of scientific concepts can function as a useful pedagogical tool, bringing both parties to a better understanding of each other's positions.

In addition, during the interview, many participants mentioned how their metaphors were based on the textbooks, which they thought provided them conceptual understanding of the sources for describing it. It would be interesting to develop a more comprehensive list of metaphors in the area of science education research from textbooks and evaluate students' reactions to them.

Clearly, there is much work to be done in the application of metaphor analysis to research in embodied experience and situated context, particularly in uncovering students' and teachers' beliefs and understandings of their scientific concepts' conceptualisation. It is hoped this study can be an early step and will serve to shed light on a meaningful framework within which to do so and a useful methodology for collecting and analysing data for more extensive studies.

REFERENCES

Abell, S. K., and Lederman, N. G. (2007) *Handbook of research on science education*. 2nd edn. New York: Routledge.

Abrahams, I., Homer, M., Sharpe, R., and Zhou, M. (2015) 'A comparative cross-cultural study of the prevalence and nature of misconceptions in physics amongst English and Chinese undergraduate students', *Research in Science and Technological Education*, 33(1), pp. 111–130.

Abrahamson, D., and Bakker, A. (2016) 'Making sense of movement in embodied design for mathematics learning', *Cognitive Research: Principles and Implications*, 1, pp. 1–13.

Abrahamson, D., and Lindgren, R. (2014) *The Cambridge Handbook of the Learning Sciences* 2nd edn. Cambrigde: Cambridge University Press.

Addido, J., Burrows, A. C., and Slater, T. F. (2022) 'Addressing pre-service teachers' misconceptions and promoting conceptual understanding through the conceptual change mode', *Problems of Education in the 21st Century*, 80(4), pp. 499–515.

Adolph, K. E., and Hoch, J. E. (2019) 'Motor development: Embodied, embedded, enculturated, and enabling', *Annual Review of Psychology*, 70, pp. 141–164.

Ahmad, S. Z., and Hussain, M. (2017) 'An investigation of the factors determining student destination choice for higher education in the United Arab Emirates', *Studies in Higher Education*, 42(7), pp. 1324–1343.

Aikenhead, G., and Jegede, O. (1999) 'Cross-cultural science education: A cognitive explanation of a cultural phenomenon', *Journal of Research in Science Teaching*, 36, pp. 269–287.

Aikenhead, G. S., and Ogawa, M. (2007) 'Indigenous knowledge and science revisited', *Cultural Studies of Science Education*, 2, pp. 539–620.

Aiyedun, O., and Jacob, O. N. (2021) 'Shortage of professional science and environmental education teachers in Nigeria', *Asian Journal of Science Education*, 3(1), pp. 1-11.

Allen, S. R. (2020) 'Intrinsicality, Independence and Grounding', *Metaphysica*, 21(1), pp. 71–97.

Allolangi, R. P., and Kurniati, A. (2023) 'Principal's Efforts to Overcome the Problem of Teaching and Learning in the Field of Science', *Jurnal Penelitian Pendidikan IPA*, 9(1), pp. 510–515.

Alsmith, A. J. T., and De Vignemont, F. (2012) 'Embodying the mind and representing the body', *Review of Philosophy and Psychology*, 3(1), pp. 1–13.

Alsop, S. (2011) 'The body bites back!', *Cultural Studies of Science Education*, 6, pp. 611–623.

Amala Arokia Nathan, R. J., Kurmi, I., and Bimber, O. (2023) ‘Drone swarm strategy for the detection and tracking of occluded targets in complex environments’, *Communications Engineering*, 2(1), pp. 55.

Amin, T. (2015) ‘Conceptual Metaphor and the Study of Conceptual Change: Research Synthesis and Future Directions’, *Conceptual metaphor and embodied cognition in science learning*, pp. 37.

Andersen, H., Barker, P., and Chen, X. (1996) ‘Kuhn’s mature philosophy of science and cognitive psychology’, *Philosophical Psychology*, 9(3), pp. 347–363.

Anderson, M. L. (2003) ‘Embodied cognition: A field guide, *Artificial Intelligence*, 149(1), pp. 91–130.

Anderson, R. C. (2018) ‘Creative engagement: Embodied metaphor, the affective brain, and meaningful learning’, *Mind, Brain, and Education*, 12(2), pp. 72–81.

Anderson, R. D. (2007) ‘Teaching the theory of evolution in social, intellectual, and pedagogical context’, *Science Education*, 91(4), pp. 664–677.

Ansah, G. N. (2013) ‘Culture in embodiment: Evidence from conceptual metaphors/metonymies of anger in Akan and English’, *Compendium of Cognitive Linguistics Research*, 2, pp. 63–82.

Ansah, M. A. (2014) ‘Language choice in multilingual communities: The case of Larteh, Ghana’, *Legon Journal of the Humanities*, 25, pp. 37–57.

Antink-Meyer, A., and Meyer, D. Z. (2016) ‘Science teachers’ misconceptions in science and engineering distinctions: Reflections on modern research examples’, *Journal of Science Teacher Education*, 27(6), pp. 625–647.

Armstrong, S. L., Gleitman, L. R., and Gleitman, H. (1983) ‘What some concepts might not be’, *Cognition*, 13(3), pp. 263–308.

Aviram, R., and Manella, G. (2020) ‘A metaphor that keeps on ticking: The ‘clock’as a driving force in the history of chronobiology research’, *Philosophy, Theory, and Practice in Biology*, pp. 12.

Avraamidou, L., and Osborne, J. (2009) ‘The role of narrative in communicating science’, *International Journal of Science Education*, 31(12), pp. 1683–1707.

Azizah, S. N., Akhsan, H., Muslim, M., and Ariska, M. (2022) ‘Analysis of college students misconceptions in astronomy using four-tier test’, *Journal of Physics: Conference Series*, 2165(1), 012004.

Bager-Elsborg, A., and Greve, L. (2019) ‘Establishing a method for analysing metaphors in higher education teaching: A case from business management teaching’, *Higher Education Research and Development*, 38(7), pp. 1329–1342.

Bakker, S., Antle, A. N., and Van Den Hoven, E. (2012) ‘Embodied metaphors in tangible interaction design’, *Personal and Ubiquitous Computing*, 16, pp. 433–449.

Barsalou, L. W. (1983) ‘Ad hoc categories’, *Memory and Cognition*, 11, pp. 211–227.

Barsalou, L. W. (1985) ‘Ideals, central tendency, and frequency of instantiation as determinants of graded structure in categories’, *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 11(4), pp. 629.

Barsalou, L. W. (1999) ‘Perceptual symbol systems’, *Behavioral and Brain Sciences*, 22(4), pp. 577–660.

Barsalou, L. W., Santos, A., Simmons, W. K., and Wilson, C. D. (2008) ‘Language and simulation in conceptual processing’, *Symbols, Embodiment, and Meaning*, pp. 245–283.

Bateson, G. (1972) ‘The logical categories of learning and communication’, *Steps to an Ecology of Mind*, pp. 279–308.

Bazeley, P. (2006) ‘The contribution of computer software to integrating qualitative and quantitative data and analyses’, *Research in the Schools,* 13(1), pp. 64–74.

Beckes, L., IJzerman, H., and Tops, M. (2015) ‘Toward a radically embodied neuroscience of attachment and relationships’, *Frontiers in Human Neuroscience*, 9, pp. 266.

Beer, R. D. (2014) ‘Dynamical systems and embedded cognition’. *The Cambridge Handbook of Artificial Intelligence*, pp. 28.

Ben-Peretz, M., Mendelson, N., and Kron, F. W. (2003) ‘How teachers in different educational contexts view their roles’, *Teaching and Teacher Education*, 19(2), pp. 277–290.

Berkes, F. (2009) ‘Indigenous ways of knowing and the study of environmental change’, *Journal of the Royal Society of New Zealand*, 39(4), pp. 151-156

Biesta, G., and Burbules, N. C. (2003) *Pragmatism and educational research*. Lanham: Rowman and Littlefield

Borghi, A. M. (2022) ‘Concepts for which we need others more: The case of abstract concepts’, *Current Directions in Psychological Science*, 31(3), pp. 238–246.

Borghi, A. M., Binkofski, F., Castelfranchi, C., Cimatti, F., Scorolli, C., and Tummolini, L. (2017) ‘The challenge of abstract concepts’, *Psychological Bulletin*, 143(3), pp. 263.

Boroditsky, L. (2001) ‘Does language shape thought?: Mandarin and English speakers’ conceptions of time’, *Cognitive Psychology*, 43(1), pp. 1–22.

Boyd, R. N. (1993) *Metaphor and theory change*. Cambrigde: Cambridge University Press

Braun, V., and Clarke, V. (2006) ‘Using thematic analysis in psychology’, *Qualitative Research in Psychology*, 3(2), pp. 77–101.

Braun, V., and Clarke, V. (2019) ‘Reflecting on reflexive thematic analysis’, *Qualitative Research in Sport, Exercise and Health*, 11(4), pp. 589–597.

Bricker, L. A., and Bell, P. (2008) ‘Conceptualisations of argumentation from science studies and the learning sciences and their implications for the practices of science education’, *Science Education*, 92(3), pp. 473–498.

Brookes, D. T., and Etkina, E. (2015) ‘The Importance of Language in Students’ Reasoning About Heat in Thermodynamic Processes’, *International Journal of Science Education*, 37(5–6), pp. 759–779.

Brooks, R. A. (1999) *Cambrian intelligence: The early history of the new AI*. Cambridge: MIT press.

Brown, B. A. (2004) ‘Discursive identity: Assimilation into the culture of science and its implications for minority students’, *Journal of Research in Science Teaching*, 41(8), pp. 810–834.

Brown, B. A., Reveles, J. M., and Kelly, G. J. (2005) ‘Scientific literacy and discursive identity: A theoretical framework for understanding science learning’, *Science Education*, 89(5), pp. 779–802.

Brown, B. A., and Ryoo, K. (2008) ‘Teaching Science as a Language: A “Content-First” Approach to Science Teaching’, *Journal of Research in Science Teaching*, 45(5), pp. 529–553.

Bryman, A. (2004) ‘The Disneyization of society’, *The Disneyization of Society*, pp. 1–200.

Buxbaum, L. J., and Kalénine, S. (2010) ‘Action knowledge, visuomotor activation, and embodiment in the two action systems’, *Annals of the New York Academy of Sciences*, 1191(1), pp. 201–218.

Caballero, R., and Ibarretxe-Antuñano, I. (2009) ‘Ways of perceiving, moving, and thinking: Revindicating culture in conceptual metaphor research’, *Cognitive Semiotics*, 5(1–2), pp. 268–290.

Cambouropoulos, E. (2001) ‘Melodic cue abstraction, similarity, and category formation: A formal model’, *Music Perception*, 18(3), pp. 347–370.

Cameron, L. (2003) *Metaphor in educational discourse*. London: Continuum.

Cameron, L. (2008) ‘Metaphor and talk’ *The Cambridge Handbook of Metaphor and Thought*, pp. 197–211.

Cameron, L. (2010) ‘What is metaphor and why does it matter. Metaphor Analysis: Research Practice in Applied Linguistics’, *Social Sciences and the Humanities*, pp. 3–25.

Cameron, L., and Maslen, R. (2010) *Metaphor analysis*. London: Equinox.

Campbell, T., McKenna, T. J., Fazio, X., Hetherington-Coy, A., and Pierce, P. (2019) ‘Negotiating coherent science teacher professional learning experiences across a university and partner school settings’, *Journal of Science Teacher Education*, 30(2), pp. 179–199.

Cantor, N., Smith, E. E., French, R. D., and Mezzich, J. (1980) ‘Psychiatric diagnosis as prototype categorisation’, *Journal of Abnormal Psychology*, 89(2), pp. 181.

Celik, H. (2016) ‘An Examination of Cross Sectional Change in Student’s Metaphorical Perceptions towards Heat, Temperature and Energy Concepts’, *International Journal of Education in Mathematics, Science and Technology*, 4(3), pp. 229–245.

Chala, A. A. (2019) ‘Practice and challenges facing practical work implementation in Natural Science subjects at secondary schools’, *Journal of Education and Practice*, 10(31), pp. 1-17.

Chen, H., Li, D., Bai, R., and Wang, X. (2018) ‘Contributions of vortical/non-vortical structures to velocity–vorticity correlations and net force in channel flow’, *Journal of the Physical Society of Japan*, 87(9), 094402.

Cheng, C.-C. (2011) *A synchronic phonology of Mandarin Chinese*. Mouton: The Hague

Cheng, M. M. H. (2011) ‘Form and structure of Chinese characters and children’s understanding of science’, *International Journal of Science and Mathematics Education*, 9(3), pp. 731–749.

Cherniak, C. (1984) ‘Computational complexity and the universal acceptance of logic’, *The Journal of Philosophy*, 81(12), pp. 739–758.

Chiu, M. (2007) ‘A National Survey of Students’ Conceptions of Chemistry in Taiwan’, *International Journal of Science Education*, 29(4), pp. 421–452.

Choi, J. W., Huh, S., and Jo, S. (2020) ‘Improving performance in motor imagery BCI-based control applications via virtually embodied feedback’, *Computers in Biology and Medicine*, 127, 104079.

Christians, C. G. (2011) ‘Primordial issues in communication ethics’, *The Handbook of Global Communication and Media Ethics*, 1, pp. 1–19.

Chu, H.-E., Martin, S. N., and Park, J. (2019) ‘A theoretical framework for developing an intercultural STEAM program for Australian and Korean students to enhance science teaching and learning’, *International Journal of Science and Mathematics Education*, 17, pp. 1251–1266.

Cibulskienė, J. (2023) ‘Scepticism voiced through extended metaphors: Assessment of higher education reform in the media’, *Metaphor and the Social World*, 13(2), pp. 197–220.

Cleeve Gerkens, R., Sallis, R., and O’Brien, A. (2023) ‘Reflecting on embodied experience through an expert lens: Drama as a pedagogic tool for developing academic language proficiency in the middle-primary school’, *Research in Drama Education: The Journal of Applied Theatre and Performance*, pp. 1–20.

Cohen, D. K., Raudenbush, S. W., and Ball, D. L. (2003) ‘Resources, instruction, and research’, *Educational Evaluation and Policy Analysis*, 25(2), pp. 119–142.

Cohen, D., and Leung, A. K.-Y. (2009) ‘The hard embodiment of culture’, *European Journal of Social Psychology*, 39(7), pp. 1278–1289.

Convertini, J., and Arcidiacono, F. (2021) ‘Embodied argumentation in young children in kindergarten’, *Education Sciences*, 11(9), pp. 514.

Cornelissen, J. (2006) ‘Metaphor in organization theory: Progress and the past’, *Academy of Management Review*, 31(2), pp. 485–488.

Cortazzi, M., and Jin, L. (1999) ‘Bridges to learning: Metaphors of teaching, learning and language’, *Researching and Applying Metaphor*, pp. 149-176.

Cortazzi, M., and Jin, L. (2020) ‘Elicited metaphor analysis: Researching teaching and learning’, in Ward, M. R., & Delamont, S. (Eds.) *Handbook of qualitative research in education*. Edward Elgar Publishing, pp. 488–505.

Creswell, J. W. (2011) ‘Controversies in mixed methods research’, in Denzin, N. K., & Lincoln, Y. S. (Eds.) *The Sage Handbook of Qualitative Research*. 4(1), pp. 269–284.

Creswell, J. W., & Clark, V. L. P. (2017) *Designing and conducting mixed methods research*. 2nd edn. Los Angeles: Sage publications.

Creswell, J. W., and Tashakkori, A. (2007) ‘Differing perspectives on mixed methods research’, *Journal of Mixed Methods Research*, 1(4), pp. 303–308.

Crick, R. D., and Grushka, K. (2009) ‘Signs, symbols and metaphor: Linking self with text in inquiry-based learning’, *The Curriculum Journal*, 20(4), pp. 447–464.

Crowther, G. J., and Knight, T. A. (2023) ‘Using test question templates to teach physiology core concepts’, *Advances in Physiology Education*, 47(2), pp. 202–214.

Czerkawski, B. C. (2016) ‘Blending formal and informal learning networks for online learning’, *International Review of Research in Open and Distributed Learning*, 17(3), pp. 138–156.

Daane, A. R., Haglund, J., Robertson, A. D., Close, H. G., and Scherr, R. E. (2018) ‘The pedagogical value of conceptual metaphor for secondary science teachers’, *Science Education*, 102(5), pp. 1051–1076.

Daher, W., and Musallam, N. (2018) ‘Objectifying the adjacent and opposite angles: A cultural historical analysis’, *International Journal of Mathematical Education in Science and Technology*, 49(2), pp. 253–267.

Dahlberg, S., Axelsson, S., Gyllensten, A. C., Sahlgren, M., Ekgren, A., Holmberg, S., and Schwarz, J. A. (2023) ‘A distributional semantic online lexicon for linguistic explorations of societies’, *Social Science Computer Review*, 41(2), pp. 308–329.

Danish, J. A., Enyedy, N., Saleh, A., and Humburg, M. (2020) ‘Learning in embodied activity framework: A sociocultural framework for embodied cognition’, *International Journal of Computer-Supported Collaborative Learning*, 15, pp. 49–87.

Davis, H. S. (2009) *Student and teacher conceptualisations of reading: A metaphor analysis study of scripted reading interventions in secondary classrooms*. University of Cincinnati.

Davis-Kean, P. E. (2005) ‘The influence of parent education and family income on child achievement: The indirect role of parental expectations and the home environment’, *Journal of Family Psychology*, 19(2), pp. 294.

De Bruin, L., and Gallagher, S. (2012) ‘Embodied simulation, an unproductive explanation: Comment on Gallese and Sinigaglia’, *Trends in Cognitive Sciences*, 16(2), pp. 98.

De Guerrero, M. C., and Villamil, O. S. (2002) ‘Metaphorical conceptualisations of ESL teaching and learning’, *Language Teaching Research*, 6(2), pp. 95–120.

de Putter-Smits, L. G., Nieveen, N. M., Taconis, R., and Jochems, W. (2022) ‘A one-year teacher professional development programme towards context-based science education using a concerns-based approach’, *Professional Development in Education*, 48(3), pp. 523-539.

de Queiroz, A. P., Bueno, A. de F., Panizzi, A. R., and Favetti, B. M. (2021) ‘Intrinsic Interspecific Competition Between Telenomus podisi and Trissolcus teretis’. *Neotropical Entomology*, 50, pp. 453–461.

DeGlopper, K. S., Russ, R. S., Sutar, P. K., and Stowe, R. L. (2023) ‘Beliefs versus resources: A tale of two models of epistemology’, *Chemistry Education Research and Practice*, 24(2), pp. 768–784.

Deignan, A. (2017) ‘From Linguistic to Conceptual Metaphors’, in Semino, E., & Demjén, Z. (Eds.) *The Routledge handbook of metaphor and language*. Abingdon: Routledge, pp. 120-134

Deignan, A., Littlemore, J., and Semino, E. (2013) *Figurative language, genre and register*. Cambridge : Cambridge University Press.

Del Maschio, N., Fedeli, D., Garofalo, G., and Buccino, G. (2021) ‘Evidence for the concreteness of abstract language: A meta-analysis of neuroimaging studies’, *Brain Sciences*, 12(1), pp. 32.

Denscombe, M. (2017) *The good research guide: For small-scale social research projects*. Maidenhead: McGraw-Hill Education.

Dewa, I., and Purwandari, R. (2021) ‘Implementation of Problem-Project Based Learning Model in Elementary School’ Proceedings of The 6th Asia-Pacific Education And Science Conference, AECon 2020, 19-20 December 2020, Purwokerto, Indonesia.

Dewey, J. (1958) *Experience and nature.* NewYork: Dover Publications.

Dimenäs, J. (2018) ‘Science teaching-scientific literacy in a school perspective’, *International Journal of Advance Research in Education and Literature*, 4(4), pp. 1–11.

diSessa, A. A. (1993) ‘Toward an Epistemology of Physics’, *Cognition and Instruction*, 10(2), pp. 105–225.

Dobson, A. P., Bradshaw, A. D., and Baker, A. J. (1997) ‘Hopes for the future: Restoration ecology and conservation biology’, *Science*, 277(5325), pp. 515–522.

Dolphin, G., and Benoit, W. (2016) ‘Students’ mental model development during historically contextualized inquiry: How the ‘Tectonic Plate’ metaphor impeded the process’, *International Journal of Science Education*, 38(2), pp. 276–297.

Dorion, K. R. (2009). ‘Science through drama: A multiple case exploration of the characteristics of drama activities used in secondary science lessons’, *International Journal of Science Education*, 31(16), pp. 2247–2270.

Dörnyei, Z. (2003) ‘Attitudes, orientations, and motivations in language learning: Advances in theory, research, and applications’, *Language Learning*, 53(S1), pp. 3–32.

Dornyei, Z. (2007) *Research methods in applied linguistics*. Oxford: Oxford university press.

Dove, G. (2009) ‘Beyond perceptual symbols: A call for representational pluralism’, *Cognition*, 110(3), pp. 412–431.

Dreyfus, H. L., and Dreyfus, S. E. (2002) ‘The challenge of Merleau-Ponty’s phenomenology of embodiment for cognitive science’ in Weiss, G., & Haber, H. F. (Eds.) *Perspectives on embodiment*. New York and London: Routledge, pp. 121–138.

Duit, R., and Treagust, D. F. (2003) ‘Conceptual change: A powerful framework for improving science teaching and learning’, *International Journal of Science Education*, 25(6), pp.671–688.

Duranti, A., and Goodwin, C. (1992) *Rethinking context: Language as an interactive phenomenon*. Cambridge: Cambridge University Press.

Durkaya, F., and LOKUMCU, G. (2022) ‘Investigation of the correlation between science teachers’ level of use of the education information network and their level of use of technology’, *Participatory Educational Research*, 9(3), pp. 263–280.

El-Sharif, A. (2023) ‘How binding and bonding communicate interpersonal meanings in a children’s museum to address Jordan’s energy and water challenges’, *Semiotica*, 2023(250), pp. 43–66.

Engelhardt, P. V., Corpuz, E. G., Ozimek, D. J., and Rebello, N. S. (2004, September) ‘The Teaching Experiment—What it is and what it isn’t’ In Aip conference proceedings (Vol. 720, No. 1, pp. 157-160). American Institute of Physics.Erman, E. (2017). Factors contributing to students’ misconceptions in learning covalent bonds. Journal of Research in Science Teaching, 54(4), 520–537.

Erreich, A., and Valian, V. (1979) ‘Children’s internal organization of locative categories’, *Child Development*, pp. 1071–1077.

Evans, N., and Wilkins, D. (2000) ‘In the mind’s ear: The semantic extensions of perception verbs in Australian languages’, *Language*, pp. 546–592.

Evans, V., and Green, M. (2009) *Cognitive linguistics: An introduction*. Edinburgh: Edinburgh University Press.

Fajriyanti, A. I., and Sayekti, I. C. (2022) ‘Misconception Analysis of the Material Science Content of the Human Circulatory System Using Concept Map Assessment in Elementary School’, *Jurnal Penelitian Pendidikan IPA*, 8(6), pp. 3146–3152.

Fang, S. (2015) ‘College EFL learners’ metaphorical perceptions of English learning’, *The Journal of Asia TEFL*, 12(3), 61–79.

Farenga, S. J., Joyce, B. A., and Ness, D. (2003) ‘Balancing the Equity Equation: The Importance of Experience and Culture in Science Learning’, *Science Scope*, 26(5), 12–14.

Fetters, M. D., and Freshwater, D (2015) ‘Publishing a methodological mixed methods research article’ *Journal of Mixed Methods Research*, 9(3), pp. 203–213.

Fitton, I. S., Finnegan, D. J., and Proulx, M. J. (2020) ‘Immersive virtual environments and embodied agents for e-learning applications’, *Peer Computer Science*, 6, pp. 315.

Fodor, J. A. (1983) *Representations: Philosophical essays on the foundations of cognitive science*. Cambridge: Mit Press.

Fox, M. J. (2011) ‘Prototype theory: An alternative concept theory for categorizing sex and gender?’ *NASKO*, 3, pp. 151–159.

Francescotti, R. (1999) ‘How to Define Intrinsic Properties’, *Noûs*, 33(4), pp. 590–609.

Furberg, A. (2016) ‘Teacher support in computer-supported lab work: Bridging the gap between lab experiments and students’ conceptual understanding’, *International Journal of Computer-Supported Collaborative Learning*, 11, pp. 89–113.

Gabora, L., & Aerts, D. (2002, May) ‘Contextualizing Concepts’, In FLAIRS, pp. 148-152.

Gallagher, S. (2006) *How the body shapes the mind*. Oxford: Clarendon Press.

Gao, L. (1998) ‘Cultural context of school science teaching and learning in the People’s Republic of China’, *Science Education*, 82(1), pp. 1–13.

Gardner, W. L., Pickett, C. L., and Knowles, M. (2013) ‘Social snacking and shielding: Using social symbols, selves, and surrogates in the service of belonging needs’ in Williams, K. D., Forgas, J. P., and Von Hippel, W. *The social outcast: Ostracism, social exclusion, rejection, and bullying*. London: Psychology Press, pp. 227-241

Gass, S., Mackey, A., and Ross-Feldman, L. (2005) ‘Task-based interactions in classroom and laboratory settings’, *Language Learning*, 55(4), pp. 575–611.

Gay, G. (2002) ‘Preparing for culturally responsive teaching’, J*ournal of Teacher Education*, 53(2), pp. 106–116.

Gazdar, G. (1979) ‘A solution to the projection problem’, in McCawley, J. D. *Presupposition and discourse structure*. Brill, pp. 57–89.

Geeraerts, D. (Ed.). (2006) *Cognitive linguistics: Basic readings*. Berlin: Mouton de Gruyter.

Gentner, D. (1983) ‘Structure-mapping: A theoretical framework for analogy’, *Cognitive Science*, 7(2), pp. 155–170.

Georgiou, Y., and Ioannou, A. (2019) ‘Embodied learning in a digital world: A systematic review of empirical research in K-12 education’, *Learning in a Digital World*, pp. 155–177.

Gerardi, D., Allen, G., Conklin, J. W., Sun, K. X., DeBra, D., Buchman, S., Gath, P., Fichter, W., Byer, R. L., and Johann, U. (2014) ‘Invited article: Advanced drag-free concepts for future space-based interferometers: Acceleration noise performance’ *Review of Scientific Instruments*, 85(1).

Gibbs, R. W. (2023) ‘How metaphors shape the particularities of illness and healing experiences’, *Transcultural Psychiatry*, 60(5), pp. 770-780.

Gibbs, R. W. (2005) ‘The psychological status of image schemas. From Perception to Meaning: Image Schemas in Cognitive Linguistics’, 29, 113–136.

Gibbs, R. W. (2009) ‘Why do some people dislike conceptual metaphor theory?’, *Cognitive Semiotics*, 5(1–2), pp. 14–36.

Gibson, J. J. (1979) ‘The Theory of Affordances’ in Gieseking, J. J., Mangold, W., Katz, C., Low, S., & Saegert, S. (Eds.) *The people, place, and space reader*. New York: Routledge, pp. 56–60.

Gilbert, J. K., Bulte, A. M., and Pilot, A. (2011) ‘Concept development and transfer in context-based science education’, *International Journal of Science Education*, 33(6), pp. 817–837.

Gilbert, J. K., and Treagust, D. F. (2009) *Multiple representations in chemical education*. NewYork: Springer.

Ginsberg, A. (1994) ‘Minding the competition: From mapping to mastery’, *Strategic Management Journal*, 15(S1), pp. 153–174.

Glaser, J., and Laudel, G. (2019) ‘The discovery of causal mechanisms: Extractive qualitative content analysis as a tool for process tracing’, 20(3).

Glenberg, A. M. (2015) ‘Few believe the world is flat: How embodiment is changing the scientific understanding of cognition’, *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale*, 69(2), pp. 165.

Glucksberg, S., Newsome, M. R., and Goldvarg, Y. (2001) ‘Inhibition of the literal: Filtering metaphor-irrelevant information during metaphor comprehension’, *Metaphor and Symbol*, 16(3–4), pp. 277–298.

Goldinger, S. D., Papesh, M. H., Barnhart, A. S., Hansen, W. A., and Hout, M. C. (2016) ‘The poverty of embodied cognition’, *Psychonomic Bulletin and Review*, 23, 959–978.

Goldman, A. I. (2012) ‘A moderate approach to embodied cognitive science’, *Review of Philosophy and Psychology*, 3, 71–88.

Golumbic, Y. N., Motion, A., Chau, A., Choi, L., D’Silva, D., Ho, J., Nielsen, M., Shi, K., Son, C. D., and Wu, O. (2022) ‘Self-reflection promotes learning in citizen science and serves as an effective assessment tool’, *Computers and Education Open*, 3, 100104.

Gouvier, W. D., and Coon, R. C. (2002) ‘Misconceptions, discrimination, and disabling language: Synthesis and review’, *Applied Neuropsychology*, 9(1), pp. 48–57.

Grady, J. (1999) ‘A typology of motivation for conceptual metaphor: Correlation vs. resemblance’ in R. W. Gibbs and G. J. Steen (Eds.) *Current Issues in Linguistic Theory*. Amsterdam: John Benjamins Publishing Company, p. 79.

Greene, J. C. (2007) *Mixed methods in social inquiry*. Hoboken: Wiley.

Gremillion, H. (2005) ‘The cultural politics of body size’, *Annual Review of Anthropology*, 34, pp. 13–32.

Gropengießer, H. (1998) ‘What language reveals about our conceptions-A case study on seeing’, *Res. Sci. Educ. Past Present Future*, 1, 140–142.

Gruenewald, D. A. (2003) ‘Foundations of place: A multidisciplinary framework for place-conscious education’, *American Educational Research Journal*, 40(3), pp. 619–654.

Gulliksen, M. S. (2017) ‘Making matters? Unpacking the role of practical aesthetic making activities in the general education through the theoretical lens of embodied learning’, *Cogent Education*, 4(1), 1415108.

Gustafson, D. L. (1998) ‘Embodied learning about health and healing: Involving the body as content and pedagogy’, Canadian Woman Studies/Les Cahiers de La Femme.

Habermas, J. (2001) *The liberating power of symbols: Philosophical essays*. New York: Mit Press.

Halloun, I. A., and Hestenes, D. (1985) ‘The initial knowledge state of college physics students’, *American Journal of Physics*, 53(11), pp. 1043–1055.

Han, T., Han, Q., Annett, M., Anderson, F., Huang, D.-Y., and Yang, X.-D. (2017) ‘Frictio: Passive kinesthetic force feedback for smart ring output’, Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology, pp. 131–142.

Han, Y., and Ginsburg, H. P. (2001) ‘Chinese and English Mathematics Language: The Relation Between Linguistic Clarity and Mathematics Performance’, *Mathematical Thinking and Learning*, 3(2–3), pp. 201–220.

Hằng, N. V. T., Meijer, M. R., Bulte, A. M., and Pilot, A. (2015) ‘The implementation of a social constructivist approach in primary science education in Confucian heritage culture: The case of Vietnam’, *Cultural Studies of Science Education*, 10, pp. 665–693.

Hardman, J., and Set, B. (2021) ‘Investigating the Double-Move in pedagogy in a Grade 4 Namibian Science Classroom: A cultural historical analysis’, *Creative Education*, 12(2), pp. 453–469.

Hart, M. (2009) *Jewish Blood: Reality and metaphor in history, religion and culture*. London: Routledge.

Hasyim, M., and Reyes, A. C. (2022) ‘An In Depth Understanding of Signs and Symbols in English Language. *Technoarete Transactions on Language and Linguistics*, 1(2).

Held, R., and Hein, A. V. (1958) ‘Adaptation of disarranged hand-eye coordination contingent upon re-afferent stimulation’, *Perceptual and Motor Skills*, 8(3), pp. 87–90.

Herakleioti, E., and Pantidos, P. (2016) ‘The contribution of the human body in young children’s explanations about shadow formation’, *Research in Science Education*, 46, pp. 21–42.

Hetherington, L., Hardman, M., Noakes, J., and Wegerif, R. (2018) ‘Making the case for a material-dialogic approach to science education’, *Studies in Science Education*, 54(2), pp. 141–176.

Hidalgo-Céspedes, J., Marín-Raventós, G., Lara-Villagrán, V., and Villalobos-Fernández, L. (2018) ‘Effects of oral metaphors and allegories on programming problem solving’, *Computer Applications in Engineering Education*, 26(4), pp. 852–871.

Hindriana, A. F., Setiawati, I., Abidin, Z., At’haya, A., and Karlina, L. (2023) ‘Analysis of Teachers’ and Students’ Perception of the Use of Metaphors in Biology’, *Jurnal Penelitian Pendidikan IPA*, 9(10), pp. 8124–8130.

Hogan, D., and O’Flaherty, J. (2021) ‘Addressing education for sustainable development in the teaching of science: The case of a biological sciences teacher education program’, *Sustainability*, 13(21), 12028.

Holstein, J. A., and Gubrium, J. F. (1995) *The active interview*. Los Angeles: Sage.

Horowitz, A. D., and Bedford, E. (2017) ‘Graded structure in sexual definitions: Categorisations of having “had sex” and virginity loss among homosexual and heterosexual men and women’, *Archives of Sexual Behavior*, 46, pp. 1653–1665.

Hoyningen-Huene, P. (1993) *Reconstructing scientific revolutions: Thomas S. Kuhn’s philosophy of science*. Chicago: University of Chicago Press.

Huang, J. (2013) ‘A common construction pattern of English words and Chinese characters’, *Plos One*, 8(9), e74515.

Hussain, M. A., Elyas, T., and Nasseef, O. A. (2013) ‘Research paradigms: A slippery slope for fresh researchers’, *Life Science Journal*, 10(4), pp. 2374–2381.

Ibarretxe-Antuñano, I. (2013) ‘The relationship between conceptual metaphor and culture’, *Intercultural Pragmatics*, 10(2), pp. 315–339.

Ioannou, M., Georgiou, Y., Ioannou, A., and Johnson, M. (2019) ‘On the understanding of students’ learning and perceptions of technology integration in low-and high-embodied group learning’, CSCL

Ionescu, T., and Vasc, D. (2014) ‘Embodied cognition: Challenges for psychology and education’, *Procedia-Social and Behavioral Sciences*, 128, pp. 275–280.

Israel, M., and Hay, I. (2006) *Research ethics for social scientists*. Los Angeles: Sage.

Ivankova, N. V., Creswell, J. W., and Stick, S. L. (2006) ‘Using mixed-methods sequential explanatory design: From theory to practice’, *Field Methods*, 18(1), pp. 3–20.

Jacob, R., Belusko, M., Fernández, A. I., Cabeza, L. F., Saman, W., and Bruno, F. (2016) ‘Embodied energy and cost of high temperature thermal energy storage systems for use with concentrated solar power plants’, *Applied Energy*, 180, pp. 586–597.

Jad, N., Raouf, K., Chibouba, N., Elkababi, K., and Radid, M. (2021) ‘Analysis learners’ pepresentations of the concept of “electricity” in 6th year of primary school’, *Journal of Southwest Jiaotong University*, 56(4).

Jahic Pettersson, A., Danielsson, K., and Rundgren, C.-J. (2020) ‘Traveling nutrients’: How students use metaphorical language to describe digestion and nutritional uptake’, *International Journal of Science Education*, 42(8), pp. 1281–1301.

Jakobson, B., and Wickman, P.-O. (2007) ‘Transformation through language use: Children’s spontaneous metaphors in elementary school science’, *Science and Education*, 16, pp. 267–289.

Jakobsson, A., and Davidsson, E. (2012) ‘Using sociocultural frameworks to understand the significance of interactions at science and technology centers and museums’ in Davidsson, E., & Jakobsson, A. (Eds.) *Understanding interactions at science centers and museums*. Leiden: Brill

Jamrozik, A., McQuire, M., Cardillo, E. R., and Chatterjee, A. (2016) ‘Metaphor: Bridging embodiment to abstraction’, *Psychonomic Bulletin and Review*, 23, pp. 1080–1089.

Janda, L. A. (2015) ‘Cognitive linguistics in the year 2015’, *Cognitive Semantics*, 1(1), pp. 131–154.

Jegede, O. J. (1995) ‘Collateral Learning and the Eco-Cultural Paradigm in Science and Mathematics Education in Africa’, *Studies in Science Education*, 25(1), pp. 97–137.

Jin, C., Ma, Y., and Uzzi, B. (2021) ‘Scientific prizes and the extraordinary growth of scientific topics’, *Nature Communications*, 12(1), 5619.

Jin, L., and Cortazzi, M. (Eds.). (2011) *Researching Chinese Learners*. London: Palgrave Macmillan.

Johann, L., Groß, J., Messig, D., and Rusk, F. (2020) ‘Content-Based and Cognitive-Linguistic Analysis of Cell Membrane Biology: Educational Reconstruction of Scientific Conceptions’ *Education Sciences*, 10(6), 151.

Johnson, M. (1997). ‘Embodied mind and cognitive science’, in Levin, D.M. (ed.) *Language Beyond Postmodernism: Saying and Thinking in Gendlin’s Philosophy*. Chicago: Northwestern University Press, pp. 148-175.

Johnson, M. (2013) *The body in the mind: The bodily basis of meaning, imagination, and reason*. Chicago: University of Chicago press.

Johnson, M., and Rohrer, T. (2007) ‘We are live creatures: Embodiment, American pragmatism, and the cognitive organism’, *Body, Language, and Mind*, 1, pp. 17–54.

Johnson, R. B., and Onwuegbuzie, A. J. (2004) ‘Mixed methods research: A research paradigm whose time has come’, *Educational Researcher*, 33(7), pp. 14–26.

Johnson, R. B., Onwuegbuzie, A. J., and Turner, L. A. (2007) ‘Toward a Definition of Mixed Methods Research’, *Journal of Mixed Methods Research*, 1(2), pp. 112–133.

Johnson-Glenberg, M. C. (2018) ‘Immersive VR and education: Embodied design principles that include gesture and hand controls’, *Frontiers in Robotics and AI*, 5, pp. 81.

Johnson-Glenberg, M. C., Birchfield, D. A., Tolentino, L., and Koziupa, T. (2014) ‘Collaborative embodied learning in mixed reality motion-capture environments: Two science studies’, *Journal of Educational Psychology*, 106(1), pp. 86.

Johnson-Glenberg, M. C., and Megowan-Romanowicz, C. (2017) ‘Embodied science and mixed reality: How gesture and motion capture affect physics education’, *Cognitive Research: Principles and Implications*, 2(1), pp. 1–28.

Johnstone, A. H. (1982) ‘Macro and microchemistry’, *Chemistry in Britain*, 18(6), pp. 409–410.

Joldersma, C. W. (2013) ‘Neuroscience, education, and a radical embodiment model of mind and cognition’, *Philosophy of Education*, pp. 263–272.

Karlsson, A., Nygård Larsson, P., and Jakobsson, A. (2020) ‘The continuity of learning in a translanguaging science classroom’, *Cultural Studies of Science Education*, 15(1), pp. 1–25.

Kersting, M., Haglund, J., and Steier, R. (2021) ‘A Growing Body of Knowledge: On Four Different Senses of Embodiment in Science Education’, *Science and Education*, 30(5), pp. 1183–1210.

Kervinen, A., Roth, W.-M., Juuti, K., and Uitto, A. (2020) ‘The resurgence of everyday experiences in school science learning activities’, *Cultural Studies of Science Education*, 15(4), pp. 1019–1045.

Kim, D., Kim, S. L., & Barnett, M. (2021) ‘“That makes sense now!”: Bicultural middle school students’ learning in a culturally relevant science classroom’, *International Journal of Multicultural Education*, 23(2), pp. 145-172.

Kim, S. Y., and Nehm, R. H. (2011) ‘A cross-cultural comparison of Korean and American science teachers’ views of evolution and the nature of science’, *International Journal of Science Education*, 33(2), pp. 197–227.

Kim, Y., and Tscholl, M. (2021) ‘Young children’s embodied interactions with a social robot’, *Educational Technology Research and Development*, 69, pp. 2059–2081.

King, C. J. H. (2010) ‘An analysis of misconceptions in science textbooks: Earth science in England and Wales’, *International Journal of Science Education*, 32(5), pp. 565–601.

King, D., and Ritchie, S. M. (2012) ‘Learning science through real-world contexts’, *Second International Handbook of Science Education*, pp. 69–79.

Kintē, V., and Arabatzis, T. (Eds.). (2012) *Kuhn’s The structure of scientific revolutions revisited*. New York: Routledge.

Kirsh, D., and Maglio, P. (1994) ‘On distinguishing epistemic from pragmatic action’, *Cognitive Science*, 18(4), pp. 513–549.

Kiverstein, J. (2012) ‘The meaning of embodiment’, *Topics in Cognitive Science*, 4(4), pp. 740–758.

Klotz, A. C., Swider, B. W., and Kwon, S. H. (2023) ‘Back-translation practices in organizational research: Avoiding loss in translation’, *Journal of Applied Psychology*, 108(5), pp. 699.

Knudsen, S. (2003) ‘Scientific metaphors going public’, *Journal of Pragmatics*, 35(8), pp. 1247–1263.

Kontra, C., Goldin-Meadow, S., and Beilock, S. L. (2012) ‘Embodied learning across the life span’, *Topics in Cognitive Science*, 4(4), pp. 731–739.

Kontra, C., Lyons, D. J., Fischer, S. M., and Beilock, S. L. (2015) ‘Physical experience enhances science learning’, *Psychological Science*, 26(6), pp. 737–749.

Korur, E. N., and Sözen, H. (2019) ‘“A Physical Education Teacher Is Like...”: Examining Turkish Students Perceptions of Physical Education Teachers Through Metaphor Analysis’, *Lnternational Electronic Journal of Elementary Education*, 12(2), pp. 183–188.

Kövecses, Z. (2002) ‘Cognitive-linguistic comments on metaphor identification’, *Language and Literature: International Journal of Stylistics*, 11(1), pp. 74–78.

Kövecses, Z. (2005) *Metaphor in culture: Universality and variation*. Cambridge: Cambridge university press.

Kövecses, Z. (2008) ‘Conceptual metaphor theory: Some criticisms and alternative proposals’, *Annual Review of Cognitive Linguistics*, 6(1), pp. 168–184.

Kövecses, Z. (2010) ‘Metaphor, language, and culture’, *DELTA: Documentação de Estudos Em Lingüística Teórica e Aplicada*, 26(spe), pp. 739–757.

Kövecses, Z. (2019) *Ten lectures on figurative meaning-making: The role of body and context*. Leiden: Brill.

Kövecses, Z. (2020) *Extended conceptual metaphor theory*. Cambridge: Cambridge University Press.

Krippendorff, K. (2004) ‘Measuring the reliability of qualitative text analysis data’, *Quality and Quantity*, 38, pp. 787–800.

Kuipers, J., Viechnicki, G., Wright, L., and Massoud, L. A. (2008) ‘Off the page and into the classroom: Characteristics of three middle school science curriculum units in their social and cultural context of use’, Manuscript Submitted for Publication.

Kulgemeyer, C., and Wittwer, J. (2023) ‘Misconceptions in physics explainer videos and the illusion of understanding: An experimental study’, *International Journal of Science and Mathematics Education*, 21(2), pp. 417–437.

Kumashiro, K. (2002) ‘Against repetition: Addressing resistance to anti-oppressive change in the practices of learning, teaching, supervising, and researching’, *Harvard Educational Review*, 72(1), pp. 67–93.

Kuna, Á., Bochatay, N., Kim, S., and Csabai, M. (2022) ‘Being in the same boat, in two ways’, *Figurative Thought and Language in Action*, 259.

Laakso, M., Welling, P., Bukvova, H., Nyman, L., Björk, B.-C., and Hedlund, T. (2011) ‘The development of open access journal publishing from 1993 to 2009’, *PloS One*, 6(6), e20961.

Ladson-Billings, G. (1994). *The dreamkeepers*. San Francisco: JosseyBass Publishing Co.

Lahlou, H. (2016) ‘Culture and Conceptualisation of Scientific Terms: An Analysis of the Concepts’ Weight’and’Mass’’ in Arabic and French’, *The Asian Journal of Humanities*, 23(2), pp. 19–37.

Lakoff, G. (1986) ‘Classifiers as a reflection of mind’, *Noun Classes and Categorisation*, 7, pp. 13–51.

Lakoff, G. (2008) *Women, fire, and dangerous things: What categories reveal about the mind*. Chicago: University of Chicago press.

Lakoff, G., and Johnson, M. (1980a) ‘Conceptual metaphor in everyday language’, *The Journal of Philosophy*, 77(8), pp. 453–486.

Lakoff, G., and Johnson, M. (1980b) *Metaphors we live by*. Chicago: University of Chicago press.

Lakoff, G., and Johnson, M. (1980c) ‘The metaphorical structure of the human conceptual system’, *Cognitive Science*, 4(2), pp. 195–208.

Lakoff, G., Johnson, M., and Sowa, J. F. (1999) ‘Review of Philosophy in the Flesh: The embodied mind and its challenge to Western thought’, *Computational Linguistics*, 25(4), pp. 631–634.

Lamanauskas, V. (2009) ‘The process of natural science education in primary school: The importance of chemistry component’, *Research, Theory and Practice in Chemistry Didactics, XIX, 1st Part: Research Articles and Theoretical Studies*, pp. 13–20.

Lancor, R. (2015) ‘An Analysis of Metaphors Used by Students to Describe Energy in an Interdisciplinary General Science Course’, *International Journal of Science Education*, 37(5–6), pp. 876–902.

Langer, S. K. (1953) *Feeling and form*. London: Routledge and Kegan Paul.

Langton, R. and Lewis, D. (1998) ‘Defining ‘‘Intrinsic’’ ’, *Philosophy and Phenomenological Research*, 58, pp. 333–345.

Larkin, D. (2012) ‘Misconceptions about “misconceptions”: Preservice secondary science teachers’ views on the value and role of student ideas’, *Science Education*, 96(5), pp. 927–959.

Lave, J., and Wenger, E. (1991) *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge university press.

Lederman, N. G. (1992) ‘Students’ and teachers’ conceptions of the nature of science: A review of the research’, *Journal of Research in Science Teaching*, 29(4), pp. 331–359.

Lee, C.-Y., Tsai, J.-L., Chan, W.-H., Hsu, C.-H., Hung, D. L., and Tzeng, O. J. (2007) ‘Temporal dynamics of the consistency effect in reading Chinese: An event-related potentials study’, *Neuroreport*, 18(2), pp. 147–151.

Lee, I., Grover, S., Martin, F., Pillai, S., and Malyn-Smith, J. (2020) ‘Computational thinking from a disciplinary perspective: Integrating computational thinking in K-12 science, technology, engineering, and mathematics education’, *Journal of Science Education and Technology*, 29, pp. 1–8.

Leitan, N. D., and Chaffey, L. (2014) ‘Embodied cognition and its applications: A brief review’, *Sensoria: A Journal of Mind, Brain and Culture*, 10(1), pp. 3–10.

Lemke, J. L. (2001) ‘Articulating communities: Sociocultural perspectives on science education’, *Journal of Research in Science Teaching*, 38(3), pp. 296–316.

Lemmi, C., Brown, B. A., Wild, A., Zummo, L., and Sedlacek, Q. (2019) ‘Language ideologies in science education’, *Science Education*, 103(4), pp. 854–874.

Leung, A. K. -y, Qiu, L., Ong, L., and Tam, K.-P. (2011a) ‘Embodied cultural cognition: Situating the study of embodied cognition in socio-cultural contexts’, *Social and Personality Psychology Compass*, 5(9), pp. 591–608.

Leung, A. K. -y., Qiu, L., Ong, L., and Tam, K.-P. (2011b) ‘Embodied Cultural Cognition: Situating the Study of Embodied Cognition in Socio-Cultural Contexts: Embodied Cultural Cognition’, *Social and Personality Psychology Compass*, 5(9), pp. 591–608.

Vygotsky, L. S. (1962) *Thought and Language*. Cambridge, MA: MIT Press.

Lewandowsky, S., Ecker, U. K., Seifert, C. M., Schwarz, N., and Cook, J. (2012) ‘Misinformation and its correction: Continued influence and successful debiasing’, *Psychological Science in the Public Interest*, 13(3), pp. 106–131.

Li, H., Forbes, A., and Yang, W. (2021) ‘Developing culturally and developmentally appropriate early STEM learning experiences’, *Early Education and Development*, 32(1), pp. 1–6.

Li, Z., and Xu, Y. (2021) ‘Sustaining the effective use of materials in language classrooms: A conceptual understanding of teacher knowledge for materials use’, *Sustainability*, 13(14), 8115.

Liamputtong, P. (2009). ‘Qualitative data analysis: Conceptual and practical considerations’, *Health Promotion Journal of Australia*, 20(2), pp. 133–139.

Liljestrand, J., Havulinna, A., Paju, S., Männistö, S., Salomaa, V., and Pussinen, P. (2015) ‘Missing teeth predict incident cardiovascular events, diabetes, and death’, *Journal of Dental Research*, 94(8), pp. 1055–1062.

Lim, C. S. (2007) ‘Characteristics of mathematics teaching in Shanghai, China: Through the lens of a Malaysian’, *Mathematics Education Research Journal*, 19(1), pp. 77–88.

Lin, P., Song, Q., Wu, Y., and Pi, J. (2019) ‘Discovering patterns for fact checking in knowledge graphs’, *Journal of Data and Information Quality*,11(3), pp. 1–27.

Lindblom, J. (2007) ‘Minding the body: Interacting socially through embodied action’, Linko¨ping: Linko¨ping University dissertation, Linko¨ping Studies in Science and Technology.

Lindblom, J. (2020) ‘A radical reassessment of the body in social cognition’, *Frontiers in Psychology*, 11, 484818.

Lindgren, R., and Johnson-Glenberg, M. (2013) ‘Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality’, *Educational Researcher*, 42(8), pp. 445–452.

Lindgren, R., & Tscholl, M. (2014) ‘Enacted misconceptions: Using embodied interactive simulations to examine emerging understandings of science concepts’, Learning and Becoming in Practice: The International Conference of the Learning Sciences (ICLS) 2014, 1(January), pp. 341–347.

Lindgren, R., Tscholl, M., Wang, S., and Johnson, E. (2016) ‘Enhancing learning and engagement through embodied interaction within a mixed reality simulation’, *Computers and Education*, 95, pp. 174–187.

Littlemore, J., & Taylor, J. R. (2014) *The Bloomsbury companion to cognitive linguistics*. London: Bloomsbury Publishing

Littlemore, J. (2017) ‘Metaphor use in educational contexts: Functions and variations’, in Semino, E., & Demjén, Z. (Eds.) *The Routledge handbook of metaphor and language*. London: Routledge, pp. 301–313.

Low, G., and Cameron, L. (1999) *Researching and applying metaphor*. Cambridge: Cambridge University Press.

Lubben, F., Netshisaulu, T., and Campbell, B. (1999) ‘Students’ use of cultural metaphors and their scientific understandings related to heating’, *Science Education*, 83(6), pp. 761–774.

Lugo-Lugo, C. R. (2012) ‘A prostitute, a servant, and a customer-service representative: A Latina in academia’ in y Muhs, G. G., Niemann, Y. F., González, C. G., & Harris, A. P. (Eds.) *Presumed incompetent: The intersections of race and class for women in academia*. Colorado: University Press of Colorado, pp. 40–49

Luna, M. J. (2018) ‘What does it mean to notice my students’ ideas in science today?: An investigation of elementary teachers’ practice of noticing their students’ thinking in science’, *Cognition and Instruction*, 36(4), pp. 297–329.

Lundgren, L., Crippen, K. J., and Bex, R. T. (2022) ‘Social media interaction as informal science learning: A comparison of message design in two niches’, *Research in Science Education*, 52(1), pp. 1–20.

Maalej, Z. (2004) ‘Figurative language in anger expressions in Tunisian Arabic: An extended view of embodiment’, *Metaphor and Symbol*, 19(1), pp. 51–75.

Macalalag, A. Z., Johnson, J., and Lai, M. (2020) ‘How do we do this: Learning how to teach socioscientific issues’, *Cultural Studies of Science Education*, 15(2), pp. 389–413.

Machery, E., Olivola, C. Y., Cheon, H., Kurniawan, I. T., Mauro, C., Struchiner, N., and Susianto, H. (2023) ‘Is identity essentialism a fundamental feature of human cognition?’, *Cognitive Science*, 47(5), e13292.

Mack, N., Ramirez, C. B., Friedland, B., and Nnko, S. (2013) ‘Lost in translation: Assessing effectiveness of focus group questioning techniques to develop improved translation of terminology used in HIV prevention clinical trials’, *PloS One*, 8(9), e73799.

Maddock, L., Boalch, G., and Harbour, D. (1981) ‘Populations of phytoplankton in the western English Channel between 1964 and 1974’, *Journal of the Marine Biological Association of the United Kingdom*, 61(3), pp. 565–583.

Magnani, L., and Nersessian, N. J. (Eds.). (2002) *Model-Based Reasoning: Science, Technology, Values*. New York: Springer.

Mahaffy, P. (2006) ‘Moving chemistry education into 3D: A tetrahedral metaphor for understanding chemistry. Union Carbide Award for Chemical Education’, *Journal of Chemical Education,* 83(1), pp. 49.

Maison, M., Darmaji, D., Kurniawan, D. A., Astalini, A., Dewi, U. P., and Kartina, L. (2019) ‘Analysis of science process skills in physics education students’, *Jurnal Penelitian Dan Evaluasi Pendidikan*, 23(2), pp. 197–205.

Malinverni, L., and Pares, N. (2014) ‘Learning of abstract concepts through full-body interaction: A systematic review’, *Journal of Educational Technology and Society*, 17(4), pp. 100–116.

Mansour, N. (2013) ‘Modelling the sociocultural contexts of science education: The teachers’ perspective’, *Research in Science Education*, 43(1), pp. 347-369.

Marsh, O. M. (2018) “ Nah, musing is fine. You don’t have to be’doing science’”: Emotional and descriptive meaning-making in online non-professional discussions about science.

Marsh, O. M. (2018). “Nah, musing is fine. You don’t have to be ‘doing science’”: emotional and descriptive meaning-making in online non-professional discussions about science (Doctoral thesis, University College London, London, England). Retrieved from http://discovery.ucl.ac.uk/10044289/

Marshall, D. (2021) ‘Intrinsicality and the classification of uninstantiable properties’, *Philosophical Studies*, 178, pp. 731–753.

Masfuah, S., Fakhriyah, F., Wilujeng, I., and Rosana, D. (2021) ‘Diagnostic test profile of scientific literacy to measure student’s misconceptions in science concept course’, *ELEMENTARY: Islamic Teacher Journal*, 9(1), pp. 35–56.

Mavuru, L., and Ramnarain, U. (2020a) ‘Learners’ socio-cultural backgrounds and science teaching and learning: A case study of township schools in South Africa’, *Cultural Studies of Science Education*, 15(4), pp. 1067–1095.

Mavuru, L., and Ramnarain, U. D. (2020b) ‘Language affordances and pedagogical challenges in multilingual grade 9 natural sciences classrooms in South Africa’, *International Journal of Science Education*, 42(14), pp. 2472–2492.

Maxcy, S. J. (2003) ‘The new pragmatism and social science and educational research’, in Samier, E. (Ed.) *Ethical foundations for educational administration*. London: Routledge, pp. 155–177.

Mayring, P. (2004) ‘Qualitative content analysis’, *A Companion to Qualitative Research*, 1(2), pp. 159–176.

McCain, K., and Kampourakis, K. (Eds.). (2019) *What is scientific knowledge? An introduction to contemporary epistemology of science*. Routledge.

McCloskey, M., and Glucksberg, S. (1979) ‘Decision processes in verifying category membership statements: Implications for models of semantic memory’, *Cognitive Psychology,* 11(1), pp. 1–37.

McComas, W. F. (2004) ‘Keys to teaching the nature of science’, *The Science Teacher*, 71(9), pp. 24.

McHugh, M. L. (2013) ‘The chi-square test of independence’, *Biochemia Medica*, 23(2), pp. 143–149.

McKenzie, E., Irwin, F., Ranganathan, J., Hanson, C., Kousky, C., Bennett, K., Ruffo, S., Conte, M., Salzman, J., and Paavola, J. (2011) ‘Incorporating ecosystem services in decisions’, in P Kareiva, H Tallis, T Ricketts, G Daily, *Natural Capital: Theory and Practice of Mapping Ecosystem Services*. Oxford: Oxford University Press, pp 339–355

McWayne, C. M., and Melzi, G. (2023) ‘Young children co-constructing science: The importance of their families and cultural communities’, *Science Education*, 107(6), pp. 1655–1669.

Meier, B. P., Schnall, S., Schwarz, N., and Bargh, J. A. (2012) ‘Embodiment in social psychology’, *Topics in Cognitive Science*, 4(4), pp. 705–716.

Memişoğlu, A. S., and Erçelik, B. (2022) ‘Determining pre-service science teachers’ perceptions of science, nature of science, and the relationship between them’, *International Journal of Contemporary Educational Research,* 9(2), pp. 378–394.

Mercer, S. (2019) ‘Language learner engagement: Setting the scene’, in Gao, X. (Ed.) *Second Handbook of English Language Teaching*. Cham, Switzerland: Springer, pp. 643–660.

Merkouris, A., Chorianopoulou, B., Chorianopoulos, K., and Chrissikopoulos, V. (2019) ‘Understanding the Notion of Friction Through Gestural Interaction with a Remotely Controlled Robot’, *Journal of Science Education and Technology*, 28(3), pp. 209–221.

Merleau-Ponty, M., and Smith, C. (1979) *Phenomenology of perception*. London: Routledge.

Mertens, D. M. (2015) ‘Mixed methods and wicked problems’, *Journal of Mixed Methods Research*, 9(1), pp. 3–6.

Mervis, C. B., Catlin, J., and Rosch, E. (1976) ‘Relationships among goodness-of-example, category norms, and word frequency’, *Bulletin of the Psychonomic Society*, 7(3), pp. 283–284.

Mervis, C. B., and Pani, J. R. (1980) ‘Acquisition of basic object categories’, *Cognitive Psychology*, 12(4), pp. 496–522.

Mervis, C. B., and Rosch, E. (1981) ‘Categorisation of natural objects’, *Annual Review of Psychology*, 32(1), pp. 89–115.

Messig, D., and Groß, J. (2018) ‘Understanding plant nutrition—The genesis of students’ conceptions and the implications for teaching photosynthesis’, *Education Sciences*, 8(3), pp. 132.

Meteyard, L., Cuadrado, S. R., Bahrami, B., and Vigliocco, G. (2012) ‘Coming of age: A review of embodiment and the neuroscience of semantics’, *Cortex*, 48(7), pp. 788–804.

Michel, H., and Neumann, I. (2016) ‘Nature of science and science content learning: The relation between students’ nature of science understanding and their learning about the concept of energy’, *Science and Education*, 25, pp, 951–975.

Miles, M. B., Huberman, A. M., and Saldana, J. (2014). *Qualitative Data Analysis, A Method Sourcebook*. 3rd edn. USA: Sage Publications.

Milne, C., and Scantlebury, K. (2019) *Material practice and materiality: Too long ignored in science education*. Springer.

Mohammed, S. H., and Kinyó, L. (2022) ‘The cross-cultural validation of the technology-enhanced social constructivist learning environment questionnaire in the Iraqi Kurdistan Region’, *Research and Practice in Technology Enhanced Learning*, 17(1), pp. 25.

Montes-y-Gómez, M., Gelbukh, A., and López-López, A. (2002) ‘Text mining at detail level using conceptual graphs’, Proc. Int’l Conf. Complex Systems, pp. 122-136.

Moodley, K., and Gaigher, E. (2019) ‘Teaching electric circuits: Teachers’ perceptions and learners’ misconceptions’, *Research in Science Education*, 49(1), pp. 73–89.

Moore, G. E., Baldwin, T., & Baldwin, T. (1903) *Principia ethica*. Cambridge: Cambridge University Press

Morrissey, K. R., Liu, M., Kang, J., Hallett, D., and Wang, Q. (2016) ‘Cross-cultural and intra-cultural differences in finger-counting habits and number magnitude processing: Embodied numerosity in Canadian and Chinese university students', *Journal of Numerical Cognition*, 2(1), pp.1-19.

Moss, D. (2017) 'Experimental philosophy, folk metaethics and qualitative methods', *Teorema: Revista Internacional de Filosofía*, pp. 185–203.

Muijs, D. (2010). *Doing quantitative research in education with SPSS.* Sage

Mullis, I. V., Martin, M. O., Foy, P., Kelly, D. L., and Fishbein, B. (2020) 'TIMSS 2019 international results in mathematics and science'.

Munn, P., and E. Drever. (2004) 'Using questionnaires in smallscale research: A beginner's guide', Rev. ed. Glasgow: The SCRE Centre, University of Glasgow

National Research Council. (2012) *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington: National Academies Press.

Negrea-Busuioc, E., Ștefăniță, O., and Guiu, G. (2022) 'Science Meets Metaphor: Teaching and Communicating about Abstract Concepts in Romanian Science Textbooks', *Romanian Journal of Communication and Public Relations,* 24(1), pp. 47-60.

Neresini, F., Dimopoulos, K., Kallfass, M., and Peters, H. P. (2009) 'Exploring a black box: Cross-national study of visit effects on visitors to large physics research centers in Europe', *Science Communication*, 30(4), pp. 506–533.

Nestojko, J. F., Finley, J. R., and Roediger III, H. L. (2013) 'Extending cognition to external agents', *Psychological Inquiry*, 24(4), pp. 321–325.

Newell, A., and Simon, H. A. (1972) *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.

Nguyen, D. J., and Larson, J. B. (2015) 'Don't forget about the body: Exploring the curricular possibilities of embodied pedagogy', *Innovative Higher Education*, 40, pp. 331–344.

Niebert, K., Marsch, S., and Treagust, D. F. (2012) 'Understanding needs embodiment: A theory-guided reanalysis of the role of metaphors and analogies in understanding science', *Science Education*, 96(5), pp. 849–877.

Niedenthal, P. M., Barsalou, L. W., Winkielman, P., Krauth-Gruber, S., and Ric, F. (2005) 'Embodiment in attitudes, social perception, and emotion', *Personality and Social Psychology Review*, 9(3), pp. 184–211.

Nokele, A. B. (2014) 'Identifying conceptual metaphors using the metaphor identification procedure vrije universiteit (MIPVU)', *South African Journal of African Languages*, 34(1), pp. 75-86.

Nosofsky, R. M. (1988) 'Similarity, frequency, and category representations', *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 14(1), pp. 54-65.

Nursa'adah, E., Liliasari, L., Mudzakir, A., and Barke, H. D. (2018) 'The Model of Educational Reconstruction: Students Conceptual Knowledge on Solid State Chemistry Domain', *Jurnal Pendidikan IPA Indonesia*, 7(2), pp. 193–203.

Nyström, J. (2005) ‘The definition of partnering as a Wittgenstein family-resemblance concept’, *Construction Management and Economics*, 23(5), pp. 473–481.

Odabasi, M., Uzunboylu, H., Popova, O., Kosarenko, N., and Ishmuradova, I. (2019) ‘Science education and mobile learning: A content analysis review of the web of science database’ *International Journal of Emerging Technologies in Learning*, 14(22), pp. 4–18.

Ogunniyi, M. B. (1988) ‘Adapting western science to traditional African culture’, *International Journal of Science Education*, 10(1), pp. 1–9.

Ogunrin, O., Ogunrin, O. A., and Murray, B. J. (2016) ‘Knowledge and practice of research ethics among biomedical researchers in southern Nigerian tertiary institutions’, *J Clin Res Bioeth*, 7(1000274), 2.

Okeke, C. (2019) ‘The relevance of African traditional religion in education of the youths in secondary school in oyi local government area of Anambra state’, *Journal of African Studies and Sustainable Development*, 2(7), pp. 204-216.

Olsen, N. S., and Williamson, A. M. (2015) ‘Development of safety incident coding systems through improving coding reliability’, *Applied Ergonomics*, 51, pp. 152–162.

Onwuegbuzie, A. J., and Johnson, R. B. (2006) ‘The validity issue in mixed research’, *Research in the Schools*, 13(1), pp. 48–63.

Osborne, R. J., Bell, B. F., and Gilbert, J. K. (1983) ‘Science teaching and children’s views of the world’, *European Journal of Science Education*, 5(1), pp. 1–14.

Òtúlàjà, F. S., Cameron, A., and Msimanga, A. (2011) ‘Rethinking argumentation-teaching strategies and indigenous knowledge in South African science classrooms’, *Cultural Studies of Science Education*, 6, pp. 693–703.

Özdemir, G., and Clark, D. B. (2007) ‘An overview of conceptual change theories. Eurasia Journal of Mathematics’, *Science and Technology Education*, 3(4), pp. 351–361.

Pallotta, F., Parola, A., & Bondani, M. (2022) ‘Quantum physics at high school: a collaboration between physics researchers and teachers to design teaching - learning sequences’, Journal of Physics: Conference Series, 2297(1).

Palmer, D. K., Martínez, R. A., Mateus, S. G., and Henderson, K. (2014) ‘Reframing the debate on language separation: Toward a vision for translanguaging pedagogies in the dual language classroom’, *The Modern Language Journal*, 98(3), pp. 757–772.

Park, M.-A., Golden, K. J., Vizcaino-Vickers, S., Jidong, D., and Raj, S. (2021) ‘Sociocultural values, attitudes and risk factors associated with adolescent cyberbullying in East Asia: A systematic review’, *Cyberpsychology: Journal of Psychosocial Research on Cyberspace*, 15(1).

Parsons, E. C., and Carlone, H. B. (2013) ‘Culture and science education in the 21st century: Extending and making the cultural box more inclusive’, *Journal of Research in Science Teaching*, 50(1), pp. 1–11.

Patton, M. Q. (2002) *Qualitative research and evaluation method*s. Sage.

Pedersen, S., and Bang, J. (2016) ‘Historicizing affordance theory: A rendezvous between ecological psychology and cultural-historical activity theory’, *Theory and Psychology*, 26(6), pp. 731–750.

Peng, K., and Nisbett, R. E. (1999) ‘Culture, dialectics, and reasoning about contradiction’, *American Psychologist*, 54(9), 741-759.

Pigliucci, M., and Boudry, M. (2011) ‘Why Machine-Information Metaphors are Bad for Science and Science Education’, *Science and Education*, 20(5–6), pp. 453–471.

Plano Clark, V. L. (2017) ‘Mixed methods research’, *The Journal of Positive Psychology*, 12(3), pp. 305–306.

Popova, Y. B., and Rączaszek-Leonardi, J. (2020) ‘Enactivism and ecological psychology: The role of bodily experience in agency’, *Frontiers in Psychology*, 11, 539841.

Pouw, W. T., Van Gog, T., and Paas, F. (2014) ‘An embedded and embodied cognition review of instructional manipulatives’, *Educational Psychology Review*, 26, pp. 51–72.

Prain, V., Tytler, R., and Peterson, S. (2009) ‘Multiple representation in learning about evaporation’, *International Journal of Science Education*, 31(6), pp. 787–808.

Prasetyo, D., Marianti, A., and Alimah, S. (2021) ‘Improvement of Students’ Science Literacy Skills Using STEM-Based E-Modules’, *Journal of Innovative Science Education*, 10(2), pp. 216–221.

Pritzker, S. E. (2011) ‘The part of me that wants to grab: Embodied experience and living translation in U.S. Chinese medical education’, *Ethos*, 39(3), pp.395–413.

Pulvermüller, F. (2013) ‘How neurons make meaning: Brain mechanisms for embodied and abstract-symbolic semantics’, *Trends in Cognitive Sciences*, 17(9), pp. 458–470.

Raab, M., and Araújo, D. (2019) ‘Embodied cognition with and without mental representations: The case of embodied choices in sports’, *Frontiers in Psychology*, 10, 467232.

Rabaglia, C. D., Maglio, S. J., Krehm, M., Seok, J. H., and Trope, Y. (2016) ‘The sound of distance’, *Cognition*, 152, pp. 141–149.

Radford, L. (2005), ‘Body, tool, and symbol: Semiotic reflections on cognition’, in E. Simmt and B. Davis (eds.), Proceedings of the 2004 Annual Meeting of the Canadian Mathematics Education Study Group, Universit´e de Laval, Qu´ebec, pp. 111–117.

Rahmawati, Y., Ridwan, A., Cahyana, U., and Wuryaningsih, T. (2020) ‘The integration of ethnopedagogy in science learning to improve student engagement and cultural awareness’, *Universal Journal of Educational Research*, 8(2), pp. 662–671.

Raja, V. (2020) ‘Resonance and radical embodiment’, *Synthese*, 1–29.

Ramstead, M. J., Veissière, S. P., and Kirmayer, L. J. (2016) ‘Cultural affordances: Scaffolding local worlds through shared intentionality and regimes of attention’, *Frontiers in Psychology*, 7, 206814.

Reddy, M. J. (1979) ‘The conduit metaphor: A case of frame conflict in our language about language’, *Metaphor and thought*, 2, 164-201.

Reichling, M. J. (1993) ‘Susanne Langer’s theory of symbolism: An analysis and extension’, *Philosophy of Music Education Review*, pp. 3–17.

Reif, F. (1995) ‘Understanding and teaching important scientific thought processes’, *Journal of Science Education and Technology*, 4, pp. 261–282.

Rips, L. J., Shoben, E. J., and Smith, E. E. (1973) ‘Semantic distance and the verification of semantic relations’, *Journal of Verbal Learning and Verbal Behavior*, 12(1), pp. 1–20.

Risko, E. F., Medimorec, S., Chisholm, J., and Kingstone, A. (2014) ‘Rotating with rotated text: A natural behavior approach to investigating cognitive offloading’, *Cognitive Science*, 38(3), pp. 537–564.

Rohrer, T. (2007). ‘The body in space: dimensions of embodiment’, in T. Ziemke, J. Zlatev and R. M. Frank *Body, language and mind: Volume 1: Embodiment. Cognitive linguistics research*. New York, NY: Walter de Gruyter, pp. 339–377.

Rosch, E., and Mervis, C. B. (1975) ‘Family resemblances: Studies in the internal structure of categories’, *Cognitive Psychology*, 7(4), 573–605.

Rosch, E., Simpson, C., and Miller, R. S. (1976) ‘Structural bases of typicality effects’, *Journal of Experimental Psychology: Human Perception and Performance*, 2(4), pp. 491-502.

Rozi, F., and Rijal, S. (2023) ‘Management of Online-Based Learning Media Through The Google Classroom Application in Increasing Student Learning Interest’, *Al-Fahim: Jurnal Manajemen Pendidikan Islam*, 5(1), pp. 188–206.

Ruan, J., and Jin, L. (2012) ‘Primary school Chinese language and literacy curriculum reforms in China after 1949’, in Leung, C., & Ruan, J. (Eds.). *Perspectives on teaching and learning Chinese literacy in China*. Dordrecht: Springer Netherlands, pp. 129-140.

Russo, A. (2012) ‘The Rise of the ‘Media Museum’: Creating interactive cultural experiences through social media’, in Giaccardi, E. *Heritage and social media: Understanding heritage in a participatory culture*. London: Routledge, pp. 145-157

Saban, A., Kocbeker, B. N., and Saban, A. (2007) ‘Prospective teachers’ conceptions of teaching and learning revealed through metaphor analysis’, *Learning and Instruction*, 17(2), pp. 123–139.

Salleh, H. (2006) ‘Action research in Singapore education: Constraints and sustainability’, *Educational Action Research*, 14(4), pp. 513–523.

Salleh, R., Venville, G. J., and Treagust, D. F. (2007) ‘When a bilingual child describes living things: An analysis of conceptual understandings from a language perspective’, *Research in Science Education*, 37, pp. 291–312.

Sanches de Oliveira, G., van Es, T., and Hipólito, I. (2023) ‘Scientific practice as ecological-enactive co-construction’, *Synthese*, 202(1), 4.

Sandelowski, M. (2000) ‘Whatever happened to qualitative description?’, *Research in Nursing and Health*, 23(4), pp. 334–340.

Schönborn, K. J., Bivall, P., and Tibell, L. A. (2011) ‘Exploring relationships between students’ interaction and learning with a haptic virtual biomolecular model’, *Computers and Education*, 57(3), pp. 2095–2105.

Schubert, T. W., and Semin, G. R. (2009) ‘Embodiment as a unifying perspective for psychology’, *European Journal of Social Psychology*, 39(7), pp. 1135–1141.

Schulz, H., Angerstein, T., and van Hoorn, A. (2018) ‘Towards automating representative load testing in continuous software engineering’, Companion of the 2018 ACM/SPEC International Conference on Performance Engineering, 123–126.

Schuman-Olivier, Z., Trombka, M., Lovas, D. A., Brewer, J. A., Vago, D. R., Gawande, R., Dunne, J. P., Lazar, S. W., Loucks, E. B., and Fulwiler, C. (2020) ‘Mindfulness and behavior change’, *Harvard Review of Psychiatry*, 28(6), pp. 371–394.

Schwandt, T. A. (2001) *Dictionary of qualitative inquiry* 2nd edn. Thousand Oaks, CA: SAGE.

Scott, J. M., Rachlow, J. L., Lackey, R. T., Pidgorna, A. B., Aycrigg, J. L., Feldman, G. R., Svancara, L. K., Rupp, D. A., Stanish, D. I., and Steinhorst, R. K. (2007) ‘Policy advocacy in science: Prevalence, perspectives, and implications for conservation biologists’, *Conservation Biology*, 29–35.

Shapiro, L. (2019) *Embodied cognition*. London: Routledge.

Shapiro, L., and Stolz, S. A. (2019) ‘Embodied cognition and its significance for education’, *Theory and Research in Education*, 17(1), pp. 19–39.

Sheng, X. (2017) ‘Cultural capital, family background and education: Choosing university subjects in China’. *British Journal of Sociology of Education*, 38(5), 721-737.

Shi, P. (2021) *Critical thinking in academic writing: A cultural approach*. London: Routledge.

Shilling, C. (2016) *The Body: A very short introduction*. Oxford: Oxford university press.

Shumba, O. (1995) ‘Interaction of traditional socio-cultural variables with instructional ideology and knowledge of the nature of science: A review of the literature with implications for Zimbabwe’, *Zimbabwe Journal of Educational Research*, 7(1), pp. 23–56.

Simayi, A. & Webb, P. (2019) *Asibizi: Teaching human reproduction in rural Eastern Cape schools*. Manchester: EasyChair.

Sinha, C., and López, K. J. de. (2001) ‘Language, culture, and the embodiment of spatial cognition’, *Cognitive Linguistics*, 11(1-2), pp. 17-41.

Smith, E. E., and Medin, D. L. (1981) *Categories and concepts*. Cambridge: Harvard University Press.

Smith, L. B., and Thelen, E. (2003) 'Development as a dynamic system', *Trends in Cognitive Sciences*, 7(8), pp. 343–348.

Soh, T. M. T., and Meerah, T. S. M. (2013) 'Outdoor education: An alternative approach in teaching and learning science', *Asian Social Science*, 9(16), pp. 1-8.

Solano-Flores, G., and Nelson-Barber, S. (2001) 'On the cultural validity of science assessments', *Journal of Research in Science Teaching*, 38(5), pp. 553–573.

Song, Y., and Carheden, S. (2014) 'Dual meaning vocabulary (DMV) words in learning chemistry', *Chemistry Education Research and Practice*, 15(2), pp. 128–141.

Sotero, M. C., Alves, Â. G. C., Arandas, J. K. G., and Medeiros, M. F. T. (2020) 'Local and scientific knowledge in the school context: Characterization and content of published works', *Journal of Ethnobiology and Ethnomedicine,* 16, pp. 1–28.

Sparrow, B., Liu, J., and Wegner, D. M. (2011) 'Google effects on memory: Cognitive consequences of having information at our fingertips', *Science,* 333(6043), pp. 776–778.

Steen, G. J. (1999) 'From linguistic to conceptual metaphor in five steps', In R. W. Gibbs and G. J. Steen (Eds.) *Current Issues in Linguistic Theory*. Amsterdam: John Benjamins Publishing Company.

Steen, G. J., and Gibbs Jr, R. W. (1999) *Metaphor in cognitive linguistics*. (downloaded:17 June 2022).

Stolz, S. A. (2015) 'Embodied learning', *Educational Philosophy and Theory,* 47(5), pp. 474–487.

Subramaniam, K. (2014) 'Student teachers' conceptions of teaching biology', *Journal of Biological Education*, 48(2), pp. 91–97.

Sung, W., Ahn, J., and Black, J. B. (2017) 'Introducing computational thinking to young learners: Practicing computational perspectives through embodiment in mathematics education', *Technology, Knowledge and Learning,* 22, pp. 443–463.

Sungur, S., Tekkaya, C., and Geban, Ö. (2001) 'The Contribution of Conceptual Change Texts Accompanied by Concept Mapping to Students' Understanding of the Human Circulatory System', *School Science and Mathematics*, 101(2), pp. 91–101.

Sutherland, D., and Swayze, N. (2012) 'The importance of place in indigenous science education', *Cultural Studies of Science Education*, 7(1), pp. 83–92.

Szu, E., Osborne, J., and Patterson, A. D. (2017) 'Factual accuracy and the cultural context of science in popular media: Perspectives of media makers, middle school students, and university students on an entertainment television program', *Public Understanding of Science*, 26(5), pp. 596–611.

Tang, K.-S. (2011) ‘Reassembling curricular concepts: A multimodal approach to the study of curriculum and instruction’, *International Journal of Science and Mathematics Education*, 9, pp. 109–135.

Tang, K.-S. (2022) ‘Material inquiry and transformation as prerequisite processes of scientific argumentation: Toward a social-material theory of argumentation’, *Journal of Research in Science Teaching*, 59(6), pp. 969–1009.

Tang, K.-S. (2024) ‘Exploring the materiality of science learning: Analytical frameworks for examining interactions with material objects in science meaning-making’, *Research in Science and Technological Education*, 42(1), pp. 32–53.

Tang, X., Qi, S., Wang, B., Jia, X., and Ren, W. (2017) ‘The temporal dynamics underlying the comprehension of scientific metaphors and poetic metaphors’, *Brain Research*, 1655, pp. 33–40.

Tanga, P. T., and Nyasha, K. (2017) ‘Diverse perceptions of cross-racial adoption in South Africa’, *Research on Social Work Practice*, 27(2), pp. 231–238.

Tao, A., Zhou, Q., Lau, N., and Liu, H. (2013) ‘Chinese American immigrant mothers’ discussion of emotion with children: Relations to cultural orientations’, *Journal of Cross-Cultural Psychology*, 44(3), pp. 478–501.

Tashakkori, A., and Creswell, J. W. (2007) ‘Exploring the nature of research questions in mixed methods research’, *Journal of Mixed Methods Research*, 1(3), pp. 207–211.

Taylor, P. C., Taylor, E., and Luitel, B. C. (2012) ‘Multi-paradigmatic transformative research as/for teacher education: An integral perspective’, *Second International Handbook of Science Education*, pp. 373–387.

Teddlie, C., and Tashakkori, A. (2009) *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences*. SAGE.

Thorburn, M., and Stolz, S. A. (2020) ‘Understanding experience better in educational contexts: The phenomenology of embodied subjectivity’, *Cambridge Journal of Education*, 50(1), pp. 95–105.

Tobin, K. (1990) ‘Changing metaphors and beliefs: A master switch for teaching?’, *Theory into Practice*, 29(2), pp. 122–127.

Topolinski, S. (2012) ‘The sensorimotor contributions to implicit memory, familiarity, and recollection’, *Journal of Experimental Psychology: General*, 141(2), pp. 260-281.

Torres, A. C., Paiva, J., & Mouraz, A. (2021) ‘High School Students ’ Questions About Science and Religion in School Debates with Scientists’, *EURASIA Journal of Mathematics, Science and Technology Education*, 17(6).

Tramowsky, N., Messig, D., and Groß, J. (2022) ‘Students’ conceptions about animal ethics: The benefit of moral metaphors for fostering decision-making competence’, *International Journal of Science Education*, 44(3), pp. 355–378.

Tramutoli, R. (2020) ‘A cultural linguistic analysis of Swahili body metaphors’, *International Journal of Language and Culture*, 7(2), pp. 257–273.

Türker, E. (2013) ‘A corpus-based approach to emotion metaphors in Korean: A case study of anger, happiness, and sadness. Review of Cognitive Linguistics’, Published under the Auspices of the Spanish Cognitive Linguistics Association, 11(1), pp. 73–144.

Tversky, B., and Chou, J. Y. (2011) ‘Creativity: Depth and breadth’, *Design Creativity*, pp. 209–214.

Vallotton, C. D., and Ayoub, C. C. (2010) ‘Symbols build communication and thought: The role of gestures and words in the development of engagement skills and social-emotional concepts during toddlerhood’, *Social Development*, 19(3), pp. 601–626.

Versteeg, M., Hafkemeijer, A., de Beaufort, A. J., and Steendijk, P. (2021) ‘An Understanding of (Mis) understanders: Exploring the underlying mechanisms of concept learning using functional magnetic resonance imaging’, *Mind, Brain, and Education*, 15(1), pp. 129–138.

Villamil, O. S., and de Guerrero, M. C. (2005) ‘Constructing theoretical notions of L2 writing through metaphor conceptualisation’, in Bartels, N. *Applied linguistics and language teacher education*. Boston, MA: Springer.

Vosniadou, S., and Brewer, W. F. (1992) ‘Mental models of the earth: A study of conceptual change in childhood’, *Cognitive Psychology*, 24(4), pp. 535–585.

Vosniadou, S., Skopeliti, I., and Ikospentaki, K. (2005) ‘Reconsidering the role of artifacts in reasoning: Children’s understanding of the globe as a model of the earth’, *Learning and Instruction*, 15(4), pp. 333–351.

Vosniadou, S., Vamvakoussi, X., and Skopeliti, I. (2008) ‘The framework theory approach to the problem of conceptual change’, *International Handbook of Research on Conceptual Change*, 1, pp. 3–34.

Vygotsky, L. (1934). *Thought and language*. Harmondsworth: Penguin Education.

Vygotsky, L. S., and Cole, M. (1978). *Mind in society: Development of higher psychological processes*. Cambridge: Harvard university press.

Wade, C. B., Koc, M., Searcy, A., Coogle, C., & Walter, H. (2023) ‘STEAM Activities in the Inclusive Classroom: Intentional Planning and Practice’, *Education Sciences*, 13(11), pp. 1161.

Walsh, Y., Magana, A. J., and Feng, S. (2020) ‘Investigating Students’ Explanations about Friction Concepts after Interacting with a Visuohaptic Simulation with Two Different Sequenced Approaches’, *Journal of Science Education and Technology*, 29(4), pp. 443–458.

Wan, W. (2012). *Using Metaphorical Conceptualisation to Construct and Develop ESL Students' Writing: An Exploratory Study*, Doctoral dissertation, University of York.

Wan, W., and Low, G. (2015) *Elicited Metaphor Analysis in Educational Discourse*. John Benjamins Publishing Company.

Wan, W., Low, G. D., and Li, M. (2011) ‘From students’ and teachers’ perspectives: Metaphor analysis of beliefs about EFL teachers’ roles’, *System*, 39(3), pp. 403–415.

Wang, J., and Wildman, L. (1995) ‘An empirical examination of the effects of family commitment in education on student achievement in seventh grade science’, *Journal of Research in Science Teaching*, 32(8), pp. 833-837.

Wang, S., Wang, H., and Weldon, P. (2007) ‘Bibliometric analysis of English-language academic journals of China and their internationalization’, *Scientometrics*, 73(3), pp. 331–343.

Weade, R., and Ernst, G. (1990) ‘Pictures of life in classrooms, and the search for metaphors to frame them’, *Theory into Practice*, 29(2), pp. 133–140.

Weatherson, B. (2001) ‘Intrinsic properties and combinatorial principles’, *Philosophy and Phenomenological Research*, 63(2), pp. 365–380.

Wenger, E. (1998) ‘Communities of practice: Learning as a social system’, *Systems Thinker*, 9(5), pp. 2–3.

Wernecke, U., Schwanewedel, J., and Harms, U. (2018) ‘Metaphors describing energy transfer through ecosystems: Helpful or misleading?’, *Science Education,* 102(1), pp. 178–194.

Wertsch, J. V. (1998). *Mind as action*. Oxford: Oxford university press.

Wertsch, J. V., and Toma, C. (2012) ‘Discourse and learning in the classroom: A sociocultural approach’, in Matthews, M. (Ed.) *Constructivism in science education: A philosophical examination*. Springer Science & Business Media, pp. 159–174).

Westbrook, S. L., and Marek, E. A. (1991) ‘A cross-age study of student understanding of the concept of diffusion’, *Journal of Research in Science Teaching*, 28(8), pp. 649-660.

Wibeck, V., Hansson, A., Anshelm, J., Asayama, S., Dilling, L., Feetham, P. M., Hauser, R., Ishii, A., and Sugiyama, M. (2017) ‘Making sense of climate engineering: A focus group study of lay publics in four countries’, *Climatic Change*, 145, pp. 1–14.

Wiberg, M., and Rolfsman, E. (2019) ‘The association between science achievement measures in schools and TIMSS science achievements in Sweden’, *International Journal of Science Education*, 41(16), pp. 2218–2232.

Wieringa, N. F., Swart, J. A., Maples, T., Witmondt, L., Tobi, H., and van der Windt, H. J. (2011) ‘Science Theatre at School: Providing a context to learn about socio-scientific issues’, *International Journal of Science Education, Part B*, 1(1), pp. 71–96.

Wilmes, S. E., Siry, C., and Tang, K.-S. (2024) ‘Drawing together international perspectives on material and embodied aspects of science education: Introduction to the Special Issue’, *Research in Science and Technological Education*, pp. 1–7.

Wilson, D. S., and Gowdy, J. M. (2015) ‘Human ultrasociality and the invisible hand: Foundational developments in evolutionary science alter a foundational concept in economics’, *Journal of Bioeconomics*, 17, pp. 37–52.

Wilson, M. (2002) ‘Six views of embodied cognition’, *Psychonomic Bulletin and Review*, 9(4), pp. 625–636.

Wilson, M. (2008) ‘How did we get from there to here? An evolutionary perspective on embodied cognition’, in Calvo, P., & Gomila, T. (Eds.) *Handbook of cognitive science: An embodied approach.* Elsevier, pp. 373–393.

Yoachim, C. M., & Meltzoff, A. N. (2003). *Cause and effect in the mind of the preschool child*. Paper presented at the biennial meeting of the Cognitive Development Society.

Young-Loveridge, J. M. (1987) ‘Learning mathematics’, *British Journal of Developmental Psychology*, 5(2), 155–167.

Yu, N. (2003) ‘Chinese metaphors of thinking’, *Cognitive Linguistics*, 14(2–3), pp. 141–165.

Yu, N. (2009) *The Chinese heart in a cognitive perspective: Culture, body, and language*. Mouton De Gruyter.

Yusof, S. S. M., Ismail, A., and Aziz, N. A. A. (2022) ‘Learning algorithm concepts by developing them in educational gameplay: From the perspective of college students in Perak’, *Journal of ICT in Education*, 9(3), pp. 30–40.

Zapata, G. C., and Lacorte, M. (2007) ‘Preservice and inservice instructors’ metaphorical constructions of second language teachers’, *Foreign Language Annals*, 40(3), pp. 521–534.

Zhang, H., and Wan, D. (2017) ‘Status of Chinese science education reforms: Policies and development framework. Chinese Science Education in the 21st Century: Policy, Practice, and Research’, 21 世纪中国科学教育:政策,实践与研究, 5-30.

Zhao, Z., and Thomas, G. P. (2016) ‘Mainland Chinese students conceptions of learning science: A phenomenographic study in Hebei and Shandong Provinces’, *International Journal of Educational Research*, 75, 76–87.

Zhou, Y., Li, X., Sing Chai, C., Tsai, C.-C., and Liang, J.-C. (2022) ‘Do parents’ conceptions of learning science predict students’ approaches to learning science and their self-efficacy for learning science?’, *International Journal of Science Education*, 44(13), pp. 2085–2109.

Zibin, A., and Hamdan, J. (2019) ‘The conceptualisation of FEAR through conceptual metonymy and metaphor in Jordanian Arabic’, *International Journal of Arabic-English Studies*, 19(2), pp. 239–262.

Zidny, R., Solfarina, S., Aisyah, R. S. S., and Eilks, I. (2021) ‘Exploring indigenous science to identify contents and contexts for science learning in order to promote education for sustainable development’, *Education Sciences*, 11(3), pp. 1-14.

Ziemke, T. (2003) ‘On the role of robot simulations in embodied cognitive science’, *AISB Journal*, 1(4), pp. 389–399.

Zinyeka, G., Onwu, G. O., and Braun, M. (2016) ‘A truth-based epistemological framework for supporting teachers in integrating indigenous knowledge into science teaching’, *African Journal of Research in Mathematics, Science and Technology Education*, 20(3), pp. 256–266.

Zwaan, R. A. (2021) ‘Two challenges to “embodied cognition” research and how to overcome them’, *Journal of Cognition*, 4(1), pp. 1-9.

APPENDIX 1 Parental Consent Form

PARENTAL CONSENT FORM

Brief Description of Research Study

The purpose of this research is to investigate your students' understanding of several scientific concepts, and how it is related to the Chinese sociocultural background. Moreover, it will also focus on how to use these effectively to promote science learning. The risks to children in this study are minimal, but the benefits could be improved attention and participation. **Please read the rest of this form before deciding if you will allow your child to be in this research study**.

My name is Xinnan Kuai and I am a PhD student at the University of Birmingham. Because you are the parent or legally authorized representative of a potential participant in my research, I am seeking your permission to let your child participate in this research study. Involvement in the study is voluntary, so you may decide whether to let your child participate or not. I will also ask your child if he or she wants to be in the study, and I will only collect information if both you and your child agree.

Before making your decision, please read the information below and ask me any questions that you have about the research; I will be happy to explain anything in greater detail.

Details of the Child's Involvement

If you agree for your child to be included, your child will need to use 20 minutes to complete a questionnaire. In the questionnaire, they need to complete the sentence "To me, this concept is like ___, because ___________". There are five physics concepts listed in this section, including force, Magnetism, Energy, mass, and volume. Then, some of the students will also be involved in a focus group of 6 students, lasting about 45 minutes. They might have the opportunity to discuss the rationale of their answer with students who share the same or different understanding. The interview will be recorded on a phone recorder. All research will be done in the free class once a day and will not interfere with their normal school science learning process.

Privacy and Confidentiality

This study will take place while children are in their school. To ensure confidentiality I will not reveal any private information about your child to anyone, unless required by law to do so. My observation records will be in my possession at all times, and only I will know which records go with which child. In any reports I make about this study, I will not use your child's name or any other information that could be used to identify him or her directly or indirectly. When my study is complete, I will destroy all of the information I collected that identifies individual students.

Risks and Benefits of Participation

Apart from taking up to 65 minutes of your child's time for investigation, we can foresee no risks for your child. Your child's involvement in the study is voluntary and he/she may withdraw from the study at any time before the deadline and withdraw any data that has been provided to that point.

Participant Rights

You have the right to ask any questions you have before, during or after the study, and I encourage you to do so. If you do not want your child to be in this study, there will be no penalties or loss of benefits that he or she is entitled to. If you agree to let your child be in this study and later change your mind, you have the right to take him or her out simply by contacting me at the email address below, and I will destroy any research data collected about your child. The deadline for withdrawing this research is 30 April, 2022.

Contact Information

For more information about this research before, during or after your participation, please contact me [redacted] or my university supervisors, Dr. Tonie Stolberg, [redacted] Dr. Donna Dawkins, [redacted] You can also report any unanticipated problems relating to the research that your child experiences during or following participation. **Please give this form to your children before February 20, 2022 if you allow your children to participate. I will come to your children's school and collect it**.

Before signing this form, please ask me any questions you have about participation in this study.

To be Completed by Parent

I have read all of the information on this form, and all of my questions and concerns about the research described above have been addressed. I choose, voluntarily, to permit my child to take part in this research study. I certify that I am at least 18 years of age.

Print name of child:

____

Print name of parent or legally authorized representative:

____

Signature of parent or legally authorized representative:

____

Date:

____

To be completed by Researcher

I confirm that the legally authorized representative of the child named above has been given an opportunity to ask questions about the study, and all the questions asked have been answered to the best of my knowledge and ability. A copy of this Consent Form has been provided to the child’s legally authorized representative, and I will keep the original for a minimum of three years.

Print name of researcher:

____

Signature of researcher:

____

Date:

____

APPENDIX 2 Child Assent Form

CHILD ASSENT FORM

Dear Student,

My name is Xinnan Kuai, and the reason for this letter is to ask if you want to be in a research study I am doing. I have already asked your parent or guardian if they will permit you to be in this study. If they did not agree, you would not be asked to sign and return this form. If they did agree, it is still your choice to make, and I am now going to describe what you will do if you agree to be in this study. If you have any questions, do ask me before you decide whether to be in the study or not.

What will you do if you are in this study?
If you want to take part in this research, you will need to use 20 minutes to complete a task. The task will include 5 terms in your textbook. During the task, you will need to express your understanding of these terms by answering “To me, this concept is like ___, because ___________”. You may be a bit strange to this type of question, don't worry, I will give you a ten-minute training session before the task to let you know how to finish this task. After the task, based on your answers in the task, some of you will also be asked to talk to me with the other 5 students for 45 minutes. You will be able to discuss with students who have the same or different understanding as you. The interview will be recorded. All the questions in the task and interview can be found in the attachment. If you have any questions, you can ask your parents or send me an email. All the tasks and interviews will be done in the free class once a day and will have no harm to your normal school science learning process. All your answers will not have any impact on your school results.

What will you do if you are not in this study?
Nothing bad will happen to you if you do not want to be in the study, and it will not hurt your grade in the class. Also, if you are not in the study, I will not ask you to finish the questionnaire and interview. While other students are completing the task or meet me for the interview, you will have time for free reading in your classroom.

Will anything bad happen to you in this study?
If you decide to be in this study, except for the task and interview you will not have any extra work, but you might feel strange about meeting individually with me or having your voice recorded. I will take special steps to make sure that you feel okay during the meeting and with the recording. You do not have to answer any questions in the questionnaire and interview that you do not want to answer. I will also make sure that you do not miss any instruction that other students get during that time.

Will anything good happen to you in this study?

You will not receive any special rewards or extra credit points for agreeing to be in this study. In other research studies like this, some students did better in class because they talked about and share their understanding of scientific concepts, and this might or might not happen for you.

Will anyone else know what you do or say in this study?

In my study, I will not use the names of any students. All information provided by you will be treated anonymously.

What if you have any questions?

Be sure to ask me any questions you have before deciding whether to be in this study or not. Even if you don’t have questions now, you can ask me about this study at any time later. If you would like time to discuss it with your parents before making your decision, please tell me.

What if you change your mind?

If you decide to be in this study and later change your mind, just tell me that you want to stop. I will stop collecting information about you for my study and will take out all of the information I already have about you. The deadline for withdrawing this research is 30 April, 2022.

To be completed by Student

To the Student: Your signature below indicates that you have read the information on this form [or that I have read the information on this form aloud to you], and that all of your questions about this research study have been answered.

Please put an X next to your decision:

___ I agree to take part in this research and I will let the researcher make a recording of what I say.
___ I DO NOT want to take part in this research.

Print name of student:

____

Signature of student:

____

Date:

____

APPENDIX 3 Teacher Consent Form

TEACHER CONSENT FORM

Brief Description of Research Study

The purpose of this research is to investigate your students' understanding of several scientific concepts, and how it is related to the Chinese sociocultural background. Moreover, it will also focus on how to use these effectively to promote science learning. The risks to you and your students in this study are minimal, but the benefits could be improved attention and participation. **Please read the rest of this form before deciding if you want to take part in this research study**.

My name is Xinnan Kuai and I am a PhD student at the University of Birmingham. I am writing to invite you to take part in my research project. Involvement in the study is voluntary, so you may decide whether you want to participate or not. Please read the information below and ask me any questions that you have about the research; I will be happy to explain anything in greater detail.

Details of the Your Involvement

If you choose to be included, some students in your class will become official participants of this research after obtaining consent from students and their parents. They will need to use 40 minutes to complete a questionnaire. In the questionnaire, they need to complete the sentence "To me, this concept is like ___, because ___________". There are five physics concepts listed in this section, including force, Magnetism, Energy, mass, and volume. This process is designed to explore how students understand these concepts, and how it is related to their bodily experiences and the Chinese sociocultural context. Then, some of the students will also be involved in a focus group of 6 students, lasting about 45 minutes. They might have the opportunity to discuss the rationale of their answer with students who share the same or different understanding. The interview will be recorded on a phone recorder.

After the student research, you need to take part in a 45-minute interview with the researcher. Prior to the interview, you will be shown the results of an anonymous preliminary data analysis. During the research process, the researcher would like you to share your understanding of students' answers in the questionnaire and interview based on your teaching experience. Your views will provide valuable information. The agenda of student questionnaire, student interview, and teacher interview can be found in the attachment. All research about students will be done in the free class once a day and will not interfere with students' normal school science learning process.

Privacy and Confidentiality

To ensure confidentiality I will not reveal any private information about you to anyone, unless required by law to do so. My observation records will be in my possession at all times. In any reports I make about this study, I will not use you, your school, and your students’ names or any other information that could be used to identify you directly or indirectly. When my study is complete, I will destroy all of the information I collected that identifies individual teachers and students.

Risks and Benefits of Your Participation

Apart from sharing your interpretation of the questionnaire and interview results, we can foresee no risks for you. Your involvement in the study is voluntary and you may withdraw your participation from the study at any time before the deadline and withdraw any data that you have provided to that point. Refusal to participate in the study will not affect your relationship with researchers of the University of Birmingham.

Your Rights

You have the right to ask any questions you have before, during or after the study, and I encourage you to do so. If you do not want to be in this study, there will be no penalties or loss of benefits. If you agree to participate in this study and later change your mind, you have the right to withdraw by contacting me at the email address below, and I will destroy any research data collected before. The deadline for withdrawing this research is 30 April, 2022.

Contact Information

For more information about this research before, during or after your participation, please contact me [redacted] or my university supervisors, Dr. Tonie Stolberg, [redacted] Dr. Donna Dawkins, [redacted] You have until February 20, 2022 to decide whether you will participate and complete this consent form. You can email me when you finish it, then I will come to your school and collect it.

To be completed by Researcher

I confirm that the teacher named below has been given an opportunity to ask questions about the study, and all the questions asked have been answered to the best of my knowledge and ability. A copy of this Consent Form has been provided to the teacher, and I will keep the original for a minimum of three years.

Print name of researcher:

____

Signature of researcher:

____

Date:

____

To be completed by Teacher

To the Teacher: Your signature below indicates that you have read the information on this form, and that all of your questions about this research study have been answered.

Please put an X next to your decision:
___ I agree to take part in this research, and I will let the researcher make a recording of what I say.
___ I DO NOT want to take part in this research.

Print name of teacher:

____

Signature of teacher:

____

Date:

____

APPENDIX 4 Participant Information Sheet for Teachers

PARTICIPANT INFORMATION SHEET FOR TEACHERS

RESEARCH TITLE: *Embodied Experiences, Sociocultural Context, and Scientific Concepts Understanding: A cognitive linguistics investigation of students' metaphor use in a Chinese primary school*

PURPOSE OF THE RESEARCH

This is an invitation for you to participate in a study conducted by researchers at the University of Birmingham. The purpose of this research is to investigate students' understanding of science concepts and how it is related to the Chinese sociocultural context. Moreover, it will also focus on how to use these effectively to promote science learning.

INVESTIGATOR

Xinnan Kuai, School of Education, [redacted]

[redacted]

SUPERVISOR

Dr. Tonie Stolberg and Dr Dawkins, School of Education

[redacted]

METHOD AND DEMANDS ON PARTICIPANTS

If you choose to be included, some students in your class will become official participants of this research after obtaining consent from students and their parents. They will need to use 20 minutes to complete a questionnaire. In the questionnaire, they need to complete the sentence "To me, this concept is like ___, because ___________". There are five physics concepts listed in this section, including force, Magnetism, Energy, mass, and volume. This process is designed to explore how students understand these concepts, and how it is related to their bodily experiences and the Chinese sociocultural context. Then, some of the students will also be involved in a focus group of 6 students, lasting about 45 minutes. They might have the opportunity to discuss the rationale of their answer with students who share the same or different understanding. The interview will be recorded on a phone recorder.

After the student research, you will need to take part in a 45-minute interview with the researcher. Prior to the interview, you will be shown the results of an anonymous preliminary data analysis. During the research process, the researcher would like you to share your understanding of students' answers in the questionnaire and interview based on your teaching experience. Your views will provide valuable information. The agenda of student questionnaire, student interview, and teacher interview can be found in the attachment. All research about students will be done in the free class once a day and will not interfere with students' normal school science learning process. The interview between you and the researcher can take place at any time you wish.

POSSIBLE RISKS, INCONVENIENCES AND DISCOMFORTS
Apart from sharing your interpretation of the questionnaire and interview results, we can foresee no risks for you. Your involvement in the study is voluntary and you may withdraw your participation from the study at any time before the deadline and withdraw any data that you have provided to that point. Refusal to participate in the study will not affect your relationship with researchers of the University of Birmingham.

BENEFITS OF THE RESEARCH
This study is a PhD project of the School of Education. It will provide valuable insights on how to improve science learning through students' daily experience and their situated sociocultural context. Findings from the study will be reported to the School of Education of my university published and possibly published in educational journals. Confidentiality is assured, you, your school, and the students will not be identified in any part of the research.

ETHICS REVIEW AND COMPLAINTS
This study has been reviewed by the Research Ethics Officer of the University of Birmingham. If you are not happy with the way this research has been conducted, you can tell your parents or the teacher who can contact the Ethics Officer at the University through aer-ethics@contacts.bham.ac.uk.

Thank you for your interest in this study.

Yours sincerely,
Xinnan Kuai

APPENDIX 5 Participant Information Sheet for Children

PARTICIPANT INFORMATION SHEET FOR CHILDREN

Dear student
I’m Xinnan, and I’m hoping you’ll agree to take part in my research to find out what you think about certain terms in your science textbooks, and how we might help you to learn science better.

WHAT WE WOULD LIKE YOU TO DO
If you want to take part in this research, you will need to use 20 minutes to complete a task. The task will include 5 terms in your textbook. During the task, you will need to express your understanding of these terms by answering “To me, this concept is like ___, because ___________”. You may be a bit strange to this type of question, don't worry, I will give you a ten-minute training session before the task to let you know how to finish this task. After the task, based on your answers in the task, some of you will also be asked to talk to me with the other 5 students for 45 minutes. You will be able to discuss with students who have the same or different understanding as you. The interview will be recorded. All the questions in the task and interview can be found in the attachment. If you have any questions, you can ask your parents to send me an email. All the tasks and interviews will be done in the free class once a day and will have no harm to your normal school science learning process. All your answers will not have any impact on your school results.

Apart from taking up your time, this research will have no risks for you. You are free to decide if you want to join us in this project or not and you can stop participating at any time before the deadline. If you decide to stop participating, any information you have given will not be used. If you decide to help us in this study, you will provide us with really important information. A report of this research will be provided to my university, but your name will not be used in any part of the research.

Yours sincerely,
Xinnan Kuai

APPENDIX 6 Letter of Information to Parents/Caregiver

LETTER OF INFORMATION TO PARENTS/CAREGIVER

Dear Parent/caregiver
Your child has been invited to participate in a research project conducted by researchers at the University of Birmingham. The project is entitled Embodied Experiences, Sociocultural Context, and Scientific Concepts Understanding: A cognitive linguistics investigation of students' metaphor use in a Chinese primary school. We write to seek your approval and assistance to conduct research and to involve your child as a participant.

PURPOSE OF THE RESEARCH
The purpose of this research is to investigate the relationship between Chinese students' understanding of science concepts and how it is related to our Chinese culture. We aim to use this to help Chinese students learn science better.

INVESTIGATOR
Xinnan Kuai, School of Education, [redacted]

SUPERVISOR
Dr. Tonie Stolberg and Dr Dawkins, School of Education
[redacted]

METHOD AND DEMANDS ON PARTICIPANTS
If you agree for your child to be included, your child will need to use 20 minutes to complete a questionnaire. In the questionnaire, they need to complete the sentence "To me, this concept is like ___, because ___________". There are five physics concepts listed in this section, including force, Magnetism, Energy, mass, and volume. This process is designed to explore how students understand these concepts, and how it is related to their daily experiences and the Chinese sociocultural context. Then, some of the students will also be involved in a 45-minute interview with other 5 students. They might have the opportunity to discuss the rationale of their answer in the questionnaire with students who share the same or different understanding. The interview will be recorded on a phone recorder for data analysis.

POSSIBLE RISKS, INCONVENIENCES AND DISCOMFORTS
Apart from taking up your child's time for investigation, we can foresee no risks for your child. Your child's involvement in the study is voluntary and he/she may withdraw from the study at any time before the deadline and withdraw any data that has been provided to that point.

BENEFITS OF THE RESEARCH

This study is a PhD project and it will provide valuable insights on promoting Chinese science education. Findings from the study will be reported to the School of Education of the University of Birmingham and possibly published in educational journals.

Confidentiality is assured, and your child will not be identified in any part of the research.

ETHICS REVIEW AND COMPLAINTS

This study has been reviewed by the Research Ethics Officer of the University of Birmingham. If you are not happy with the way this research has been conducted, you can tell your parents or the teacher who can contact the Ethics Officer at the University through aer-ethics@contacts.bham.ac.uk.

Thank you for your interest in this study.

Yours sincerely,
Xinnan Kuai

APPENDIX 7 Letter to School Headteacher

LETTER TO SCHOOL HEADTEACHER

Dear Principal

We would like to invite 480 students from grade 3, 4, 5 (160 in each grade) and 2 science teachers at your school to participate in a research project conducted by researchers at the University of Birmingham. The project is entitled Embodied Experiences, Sociocultural Context, and Scientific Concepts Understanding: A cognitive linguistics investigation of students' metaphor use in a Chinese primary school.

We write this to seek your approval and assistance in conducting research.

The purpose of the research is to investigate:
1, What conceptual metaphors do primary school students use to understand science concepts?
2, Which embodied experiences are deployed as source domains for the emergence of these metaphors?
3, How does students' use of conceptual metaphors and embodied experiences vary by grade level?

Approval is sought to conduct this research in the school for two months. There will be three parts to this research. The first part is questionnaire investigation, during which 480 student participants will need to use 40 minutes to complete a questionnaire. In the questionnaire, they need to complete the sentence "To me, this concept is like ___, because ___________". There are five physics concepts listed in this section, including force, Magnetism, Energy, mass, and volume. The second part is student focus group interview. Some of the students will be further selected based on their in the questionnaire and involved in a focus group of 6 students, lasting about 45 minutes. They might have the opportunity to discuss the rationale of their answer with students who share the same or different understanding. The interview will be recorded on a phone recorder. Each grade will have 2 focus group interviews and a total of 36 students will participants in it. The third part is the teacher interview. After the exploration of the students, two teacher participants will be involved in 45-minute interviews. Prior to the interview, they will be provided with the results of an anonymous preliminary data analysis. During the interview, the researcher would like them to share their understanding of students' answers in the questionnaire and interview based on their teaching experience. The student questionnaire, student interviews, and agenda of the teacher interviews can be found in the attachment. All research will be done in the free class once a day and will not interfere with students' normal school science learning process.

This study is a PhD project and ethics has been reviewed by the Research Ethics Officer of the University of Birmingham. Findings from the study will be reported to the School of Education of my university and possibly published in educational journals. Confidentiality is assured, you, your school, and the students will not be identified in any part of the research.

The findings of this research will provide a basis for future decisions on the development of online modules for teachers and the support required for their use. If there are any ethical concerns you can contact the Ethics Officer at the University of Birmingham through aer-ethics@contacts.bham.ac.uk.

Should you require any further information please do not hesitate to contact,

Yours sincerely,
Xinnan Kuai

School of Education
[redacted]

APPENDIX 8 Student Questionnaire

Student Questionnaire (English Version)

Dear student,

I'm a PhD student at the University of Birmingham. Through this questionnaire I wish to know more about your understanding of several words in your science textbooks. You are encouraged to use 'metaphorical' expressions in your answer like as practiced before. If you have any questions, feel free to ask me, or write them down in Section 2. This questionnaire will not have any impact on your school results. So, don't be shy, and be open to sharing your thoughts.

Please fill in the vacant content.

Concept 1: Magnet
To me, this concept is like ____________,
Because
____
_________.

Concept 2: Concave Lens
To me, this concept is like ____________,
Because
____
_________.

Concept 3: Vapour
To me, this concept is like ____________,
Because
____
_________.

Concept 4: Mercury
To me, this concept is like ____________,
Because
____
________.

Concept 5: Circuit
To me, this concept is like ____________,
Because
____
_________.

Concept 6: Gravity
To me, this concept is like ____________,
Because
____
_________.

Concept 7: Buoyancy
To me, this concept is like ____________,
Because
____
_________.

Concept 8: Energy
To me, this concept is like ____________,
Because
____
_________.

Section 2: If you have any questions, please fill in here.
____
____
____

Questionnaire Sample (Chinese Version, for conducting the research)

亲爱的参与者：
我是伯明翰大学的一名博士在读生。通过这一问卷，我希望能够更加了解你对一些科学概念的理解。像我们刚刚训练的一样，希望你能够在答案中使用一些隐喻表达。如果你有任何问题，可以随时问我，或者在问卷的第三部分写出来。这一问卷将会被妥善保存，并且它将对你的学校成绩没有任何影响。请不要害羞，大胆表达你的想法吧！

第二部分：请填写空白处

概念 1: 磁铁
我觉得，这个概念像____________,
因为____
__________.

概念 2: 凹透镜
我觉得，这个概念像____________,
因为____
__________.

概念 3: 水蒸气
我觉得，这个概念像____________,
因为____
__________.

概念 4: 水银
我觉得，这个概念像____________,
因为____
__________.

概念 5: 电路
我觉得，这个概念像____________,
因为____
__________.

概念 6: 重力
我觉得，这个概念像_____________,
因为

____

__________.

概念 7: 浮力
我觉得，这个概念像_____________,
因为

____

__________.

概念 8: 能量
我觉得，这个概念像_____________,
因为

____

__________.

第三部分：如果有任何疑问，请填写在这里

____

____

____

APPENDIX 9 Training before Completing Questionnaire

In this lesson, I will be the ‘science investigator’ and investigate your knowledge of scientific terms in an interesting way.

Do you know why a rolling ball gradually slows down and stops when no other external force is applied? If you have studied science, one of the terms that immediately comes to mind is ‘friction’.

Who can tell us what is friction like to you? Can you give an example of why you use this metaphor? I will give you an example. You can say that friction is like a hand because it can stop the car. By introducing ‘friction’ through metaphor, this abstract scientific term becomes concrete. Different people could have different understandings of the same scientific term. Who has a different idea? (Student give their answers)

Let's plug in our imagination and combine it with our life experience, so we have so many different interpretations of the same scientific term. Let's think of another scientific term "elasticity" and finish the sentence “Elasticity is like ___, because___”.

Now you have understood the interesting way to investigate your knowledge of scientific terms – using metaphors. So, take out the questionnaire, think about it, imagine it and express your research and understanding of scientific terms.

APPENDIX 10 Semi-Structured Interview Outline

Opening Question

Do you remember completing a questionnaire about scientific concept metaphors previously?

Primary Question

1, What do you think can impact the specific words you choose to describe your explanation?
2, For concepts in the questionnaire, how do you build your understanding of it?
3, What challenges did you encounter when you answered the questionnaire?

Conclusion Question

1, Summarize key points discussed during the interview.
2, Inform the interviewee about the subsequent steps in the research process.
3, Thank the interviewee for their time and insights.