Dominance Hierarchy as a Hidden Value in Biology: A Critical Discourse Analysis

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Abstract

Education researchers have analysed biology textbooks for their language and representations such as metaphors and diagrams from a conceptual lens. However, there isn't sufficient research into unpacking these metaphors to understand their ideological implications for scientific knowledge and science education. In this thesis, I perform a critical discourse analysis of introductory biology textbooks as well as popular scientific illustrations to uncover the hidden ideologies in seemingly innocent scientific concepts. Using the two cases of cellular functioning and evolutionary history, I show how dominance hierarchies pervade descriptions of concepts at various levels of organisation. Dominance hierarchy ranks the components of natural systems from 'higher' to 'lower'. At the cellular level, the conceptual metaphor of 'cell as a factory' projects the societal inequalities onto the cell with the nucleus as the 'control centre' and the cytoplasm as the site of manual labour that 'executes' the 'instructions' received. On the ecological and evolutionary levels, the representation of the ecological pyramid organises the living world into a feudal hierarchy. The conceptual metaphor of the 'ladder of life', discarded explicitly but still manifesting subtly in many ways, establishes the mammals and then humans at the top of the evolutionary 'ladder'. I will enumerate the strands of empirical research in biology that have countered the hierarchical projections at the cellular as well as evolutionary levels. Despite this research, textbook representations have continued projecting societal hierarchies onto nature. I, therefore, attempt to understand the allure of the hierarchical representations by tracing their historical and cultural roots and argue that their appeal could lie in their congruence with our theoretical frameworks, gender ideologies, and class, caste, and racial structures of our societies. I further discuss how scientific discourse, otherwise perceived as objective and value-neutral, can serve as a 'Trojan horse' for the ideology of dominance hierarchy.

Overview of the thesis

Chapter 1. Introduction

The first chapter details the background and motivation behind the study. It also recounts my personal journey during this study. The chapter situates the thesis in the larger literature in the domains of science education and science studies.

Chapter 2. Methodology

The chapter describes the methodological frameworks of critical discourse analysis that I used to probe the textbook discourse of biology. It also describes the framework of critical metaphor analysis and critical visual analysis. It outlines the selection of textbooks and other materials I analysed and the validity and reliability criteria within the paradigm of critical qualitative research.

Chapter 3. Critical discourse analysis of the textbook representation of the cell

The third chapter focuses on the textbook representation of cellular functioning. It uncovers the assumptions of hierarchical functioning in the cell with the nucleus being considered as a 'control centre' while the rest of the cell is relegated to 'manual labour'. It enumerates the wealth of research in various fields of biology that shows that the nucleus is not the only store of 'information' and that information is distributed in the cytoplasm as well. The research on organelle interaction also shows that the division of labour in the cell is not top-down and static but bottom-up and emergent. The chapter then attempts to understand the appeal of the centralised metaphor in spite of these conceptual challenges and locates these appeals in the dominant theoretical frameworks, gender ideologies, and class/caste/race structure of our societies.

Chapter 4. Critical discourse analysis of the textbook representation of evolution

The fourth chapter focuses on ecological and evolutionary hierarchy. It examines the representation of the ecological pyramid, which suggests a hierarchical structure of an ecosystem. It shows how the textbook discourse on evolutionary history implicitly upholds the hierarchy between living organisms in subtle ways. It shows that the narrative of evolutionary history with its emphasis on 'The Age of Reptiles' of the past serves an ideological role in establishing the dominance of present-day mammals. The chapter attempts to understand how the ecological pyramid and the evolutionary 'ladder of life' interact to impose a strong sense of hierarchy onto the living world. In an evolutionary sense, some organisms are suggested to be 'higher' and more 'advanced' using subtle ways. In an ecological sense, patriarchal notions of 'dominance' are used to place particular organisms 'higher' in ecosystems. Together, these hierarchies combine in the narrative of evolutionary history to suggest the organisms most 'advanced' in that particular period 'rule' the earth.

Chapter 5. Conclusions and Future Directions

The final chapter presents conclusions and discusses the pedagogical implications of the findings and analysis developed in the previous chapters. It also attempts to chart a way forward for science education research, the practice of science education, and the practice of science.

Publications based on the thesis

- Navare, C. (2021). Ink to Inkling: Artful Messages in the Visuals of Biology. In Bowen, T. & Caraway, B. (Eds). *Visual Futures: Exploring the Past, Present, and Divergent Possibilities of Visual Practice*. Bristol, UK: Intellect Books.
- Navare, C. (In press). Instructions, commands, and coercive control: A critical discourse analysis of the textbook representation of the living cell. Cultural Studies of Science Education. https://www.doi.org/10.1007/s11422-022-10123-6.

Conference presentations:

- Tyranny of T.rex: Visual Rhetoric of Prehistoric Life (September 2021)
  Paper presented at Annual Research Meet at Homi Bhabha Centre for Science Education, Mumbai, India.
- Instructions, 'Commands,' and Coercive 'Control': A Critical Discourse Analysis of Textbook Representations of the Living Cell (September 2021)
  Paper presented (remotely) at Wisconsin Symposium on Feminist Biology, University of Wisconsin-Madison, Wisconsin, USA.
- From Cell to Ecological Pyramid: How Centralised Thinking and Dominance Hierarchy Pervade in Biological Discourse (August 2020)
  Paper presented (remotely) at Society for Social Studies of Science (4S) Annual Meeting, Prague, Czech Republic.
- How's How: Cartoon Ramblings on the Philosophy and the Politics of Science (March 2019)
  Paper presented at Annual Research Meet at Homi Bhabha Centre for Science Education, Mumbai, India.
- Perception as Action: The Role of Embodiment in Understanding Visuals (May 2018)
  Paper presented at the Visual Futures Think Tank, Toronto, Canada.
- Visuals in Biology: Motion and Agency (September 2017)
  Paper presented at Society for the Social Studies of Science (4S) Annual Meeting, Boston, Massachusetts, USA.

Chapter 1. Introduction

1.1 Motivation

I began this study with a plan to analyse the visual rhetoric of biology. Values and ideologies are often not explicitly stated, but reveal themselves in aesthetic choices and what is left unsaid. My sense was that the visual representations will serve as productive sites for uncovering hidden values. I began having conversations with scientific illustrators, analysing their work and asking them questions about their thought processes when illustrating. As this work proceeded, I started paying attention to the choices that were considered as aesthetic by illustrators or choices that 'felt right'. I began to question why particular aesthetic choices are mainstream, among the many possible choices available. It appeared to me that the selected choices were not individual choices but emerged from a larger societal discourse that engendered these choices, and also determined which choices are popular and mainstream. During the early phase of my PhD, I was also introduced to the field of Feminist Science Studies (FSS), which showed me the deep roots of particular values and ideologies in not just the language but in fundamental concepts in biology. This literature helped me scrutinise the biology visuals and other representations such as metaphors from a new perspective. As I began to study the discourse surrounding biology, I widened the scope of my study to analyse the representations used such as metaphors and models. I also began to pay attention to the vocabulary, and grammatical structures of biology textbooks to understand the ideologies they are communicating using the methodology of critical discourse analysis that I detail in Chapter 2.

1.2 Literature Review

In their review of Biology Education Research (BER), Singer, Nielsen and Schweingruber (2013) comment that the major challenges that it has taken on are a) helping students achieve accurate conceptual understanding and b) studying how students interpret representations such as graphs, diagrams, and models fundamental in biology. They note that BER has focused on identifying students' misconceptions, devising ways to assess students' conceptions, and assessing the benefits of different teaching strategies. While BER studies often focus on learning and teaching the accepted knowledge in a discipline (Hsu et al, 2021), studies in the field do not often engage in problematizing the knowledge itself. Studies that focus on how the cultural assumptions and ideologies embedded in the discipline are learned and taught through it remain rare within the BER community. Such studies are typically found in cultural studies, science studies, feminist science studies journals, or isolated essays in biology research journals. This distinction, of concepts being separate from ideologies, needs to be problematized. As Science Studies and Feminist Science Studies scholars have shown, concepts are not ideology neutral and value-free. Concepts emerge from, are accepted within, and often reinforce the prevalent ideological frameworks.

Oudshoorn (2003) makes this point when she briefly recounts the feminist science studies scholarship focusing on the human body. Oudshoorn observes that the second-wave feminist movement introduced the sex-gender distinction in the 1970s. This relegated sex to the domain of biology, while gender came to be seen as the socially constructed identity. While this distinction indeed turned out to be useful, feminist biologists from the 1980s also went further to question the biological factuality of sex and showed how it is culturally constructed. Similarly, Schiebinger (1993) shows how the seemingly neutral naming and classification criteria for the class Mammalia, taught in biology education everywhere, is ideologically charged. She analyzes the choice of the name Mammalia within the political

milieu of eighteenth-century Europe. The choice of mammary glands as the distinguishing feature and the basis for the name from among the several unique characteristics of mammals might seem an arbitrary choice. Linnaeus was against the practice of employing wet nurses, prevalent in middle and upper-class women. He believed it violated the laws of nature and risked corrupting the baby because of the milk from women from lower class. By terming the class *Mammalia*, Linnaeus declared that the ability of females to nourish their offspring with milk is not only natural but fundamental to the whole class of animals. Schiebinger argues that this was a political act that aided the movement to abolish wet nursing. The example highlights how the lenses with which we observe the natural world are socioculturally constructed. Such issues are rarely discussed within science classes when the presence of mammary glands is described as the 'right' criterion for classification.

This scrutiny of biological knowledge feminists was not only restricted to the biological sex. While Oudshroom (2003) and Fausto-Sterling (2012) focused their attention on the body and the sex, other feminist biologists identified the role of assumptions in constructing knowledge about a range of biological phenomena. Feminist evolutionary biologists such as Gross and Averill (1983), Hubbard (1983), Gowaty (2003), and Roughgarden (2013) identified the patriarchal assumptions in the theories of natural selection and sexual selection. Hubbard (1983) showed that even though it is popularly considered that Darwin's genius was far ahead of his time, his theory was firmly rooted in his social milieu. Malthusian 'struggle for existence' and competition, promiscuous males pursuing coy and choosy females are some elements that did not make it difficult for Spencer's Social Darwinism to apply the evolutionary theory back to the society which had supplied its assumptions in the first place. Keller (1983) pointed out the assumptions of dominance hierarchy even at the cellular level while recounting her early work on slime mould aggregation. Slime moulds can exist as single cells as well as multicellular organisms. Single-celled slime moulds 'aggregate' to

form multicellular structures. In the1960s, the literature postulated the existence of a founder cell which provided molecular signals to initiate aggregation. Keller and Segel's (1970) simplified model, however, showed that aggregation can start with individual slime mould cells releasing more 'messenger' molecules that stimulate cell migration. The crucial difference was that in their model, changes originated locally in any cluster of cells, without the need for 'founder cells' or 'pacemakers'. Keller (1983) commented that a decade after this work, "founder cell" was still the prevalent theory in the field and she cautioned, "In our zealous desire for familiar models of explanation, we risk not noticing the discrepancies between our own predispositions and the range of possibilities inherent in natural phenomena. In short, we risk imposing on nature the very stories we like to hear." (p. 521). Bonnie Spanier (1995), in her analysis of the discourse of molecular biology from a feminist perspective, has similarly remarked that the discourse reveals an underlying commitment to natural hierarchies. She has criticised the notion of DNA as the "master molecule" that directs and controls the functioning of the cell.

Apart from feminist science studies, a philosopher of science whose work sheds light on values in science is Ludwik Fleck. Fleck (1979), in 'Genesis and Development of a Scientific Fact', argues that scientific facts are often linked to and stem from the 'prescientific' notions prevalent in the culture. In the process, the proto-ideas can get modified, as they interact with the scientific process. I will illustrate the point about pre-scientific ideas using a different example than the ones given by Fleck, one that will be more relevant to this thesis. Prete (1991) notes that early philosophers such as Aristotle believed that the beehive was ruled by a king and contained male soldier bees. Seventeenth-century naturalist Charles Butler, who believed that the beehive monarchy is "the most naturall and absolut' form of government" (as quoted in Prete, 1991, p. 128), nevertheless realised that the "king" is anatomically female. The proto-idea of the male king and male soldiers got modified as more evidence

came to light. However, despite this, the proto-idea of monarchy survives in the form of the metaphor of a "queen" bee. The hidden ideology of hierarchy that is conveyed through this metaphor, although in a more modified form, is the same as that carried by the proto-idea. It is important to uncover the proto-ideas as well as ideologies packaged within scientific concepts, because as education researchers (Bazzul and Sykes, 2011; Raveendran and Chunawala, 2015; Donovan, 2015; Jamieson and Radick, 2017) have shown, values and ideologies can get conveyed through science curriculum. Bazzul and Sykes analyse the treatment of gender, sex, and sexuality in a popularly used biology textbook. They show that through the silence regarding sexualities in the human world and in the animal world, the texts reinforce heteronormativity. Bazzul and Sykes also uncover the assumptions of binary sex and gender and how these assumptions are packaged in the "scientific" textbook discourse. Raveendran and Chunawala (2015) perform a critical analysis of higher secondary biology textbook treatment of reproductive health. Their analysis reveals an uncritical acceptance of reproductive technologies in the textbook which devalues feminist concerns about those technologies and their adverse effects. Raveendran and Chunawala also highlight the prevalence of fact-value distinction in the science textbook as well as in curricular documents. Lemke (2011) similarly argues that the partitioning of the curriculum in science and 'non-science' subjects serves as a mechanism by which reigning ideologies get uncritically transmitted through scientific discourse because an examination of the social aspects is often considered to be in the purview of social sciences or other "non-science" subjects. Scientific discourse or scientific knowledge can thus serve as a "Trojan horse" for social ideologies that value the domination of one group/entity over others. In this thesis, I will argue that dominance hierarchy is conveyed through biological discourse from the cellular level to the ecological and evolutionary levels.

Chapter 2. Methodology

2.1 Critical Discourse Analysis

To scrutinise the biology textbooks, I follow the framework of critical discourse analysis (CDA) developed by Fairclough (2001). Discourse analysis is an umbrella term for many different frameworks and perspectives, all attempting to study “language beyond the sentence” (Yule, 2020, p. 142) or “language use conceived as social practice” (Fairclough, 1993, p. 138). The strand of critical discourse analysis challenges the fundamental assumptions and uncovers societal power relations that are manifested in and reinforced through the discourse. It is premised on the conviction that language does not transparently capture the social world, but social practice and linguistic practice co-constitute each other. CDA attempts to uncover, what Fairclough (2001) describes as, “hidden power” in the discourse which serves the interests of dominant societal classes. Fairclough points out that the “hidden power” and ideologies often manifest through what we consider commonsensical and seemingly self-evident notions. Critical discourse analysis, therefore, attempts to problematize the commonsensical assumptions to reveal the ideological underpinnings. Fairclough elaborates on several features that can be used to describe the text. These are mainly divided into three categories: vocabulary, grammatical features, and textual structures. Analysis of vocabulary helps in identifying the ideologically significant word choices, the underlying classification schemes used, euphemistic expressions that avoid certain words, value judgments inherent in the words used, and so on. Analysis of grammatical features reveals how sentence structures hint at the participants' agency and causality, whether action verbs are used or nominalization is used, and how the readers are positioned in the discourse in relation to the producers. The analysis of textual structures reveals the overarching patterns regarding how the text is organised, the order of the component parts, and how they are connected. In addition to paying attention to vocabulary, grammatical features, and textual

structures, I will also draw on the tools for Discourse Analysis detailed by James Paul Gee (2010), such as the 'Fill In' tool, and 'Making Strange' tool. The 'Fill In' tool attempts to fill in the unsaid assumptions and knowledge that readers of a text are expected to possess. 'Making Strange' tool asks how an outsider, say a Martian, would understand the text—and in this process, makes explicit the assumptions in the text.

As mentioned earlier, in problematizing scientific discourse, this analysis draws upon the works of Feminist Science Studies (FSS). Works by FSS scholars have been crucial in busting the myth of science being 'objective' and 'value-free', and have shown how scientific models can project scientists' assumptions and values onto nature. These works have uncovered masculine assumptions of hierarchy, control, and dominance in scientific concepts (Keller, 1983, 1997; Spanier, 1995; Hubbard, 1983; Roughgarden, 2013). This analysis builds on these works to scrutinize how power and hierarchy manifest in biological discourse in subtle ways, and is therefore a Feminist Critical Discourse Analysis. I use feminist anthropologist Emily Martin's (1991) notion of a scientific "fairy tale" to probe scientific discourse. In the landmark paper, Martin described how the stereotypes of persistent men wooing coy women have been reflected in the scientific discourse on fertilization and the dynamics of egg and sperm. She also showed that the societal power relations projected onto the natural systems further reinforce the same power relations. The scientific fairy tale works by giving excessive focus on certain aspects (in this case, sperm motility) while neglecting or masking other aspects that do not conform to the social stereotypes (the 'choice' of the egg and the active role of the female reproductive system). Scientific fairy tales, thus, can cloak scientists' values and assumptions into scientific knowledge and are particularly pernicious because they naturalize social stereotypes using the authority of science.

2.2 Critical Metaphor Analysis

In the analysis of word choices, I pay particular attention to the metaphors used. I use the framework of critical metaphor analysis (Charteris-Black, 2004), which draws upon Lakoff and Johnson's (1980) Conceptual Metaphor Theory (CMT) and critical discourse analysis (Fairclough, 2001). According to conceptual metaphor theory (CMT), our conceptual system is fundamentally metaphorical in nature. A conceptual metaphor, according to CMT, underlies a set of metaphorical expressions. For example, consider the following metaphorical expressions that we often use: "seed of an idea", "idea is planted in the mind", "budding idea", and "idea developing and coming to fruition". All these metaphorical expressions, Lakoff and Johnson show, are based upon the underlying conceptual metaphor of 'ideas are plants'. This conceptual metaphor structures the abstract notion of ideas in terms of plants. Broadly, a conceptual metaphor 'X is Y', relates the (often) abstract X to a familiar object or phenomenon Y. This allows properties of source domain Y (plants) to be mapped onto the corresponding properties of X (ideas). Conceptual metaphors are often not explicit in a text. Analysis of word choices and explicit metaphors used in the text can indicate an underlying conceptual metaphor that relates the disparate metaphors and word choices to each other.

The framework of critical metaphor analysis also conceptualizes metaphors as rhetorical devices and analyzes them within a social context. This enables the identification of the socio-political power structures inherent in the metaphors. Charteris-Black describes a metaphor as "conscious linguistic choices that conceals underlying social processes" (2004, p. 30). Frequently used metaphors, which structure the way we think about phenomena, can thus be understood as having 'hidden power', subtly upholding the interests of dominant societal classes.

2.3 Critical Visual Analysis

As with metaphors, visual imagery is a powerful mode of communication. In the field of science education, extensive literature is available about their use as external representations (Ainsworth, 2006), pedagogical models, and ‘tools to think with’ (Kindfield, 1994). Feminist science scholars such as Tuana (2004) and Meynell (2008) have also shown how scientific illustration can be charged with ideology. Analysis of the choices regarding what is depicted and how it is depicted can reveal implicit assumptions. As Gee (2010) notes, the tools of discourse analysis can be applied to visual material as well. I use the ‘making strange’ tool to question the colour choices in diagrams and illustrations of biology that ‘feel right’. Kress and Van Leeuwen, T. (2002) argue that colour can be used as a semiotic resource to understand visuals. I provide visual descriptions of textbook diagrams and illustrations of the cell and of evolutionary history, paying close attention to aesthetic choices such as colours and layout.

2.4 Data Sources:

2.4.1 Textbooks

As I was interested in values and ideologies that are communicated to students through science textbooks, I decided to analyse popularly used biology textbooks. I chose the textbooks intended for advanced high school and introductory college courses. These textbooks are used by a wider fraction of students, not limited to students aspiring to be biologists. Since the reach and popularity of textbooks are hard to quantify or estimate, the parameter that was used here as a proxy for popularity was the rankings by the e-commerce website Amazon.com. I selected the first four general biology textbooks from the category ‘Books> Textbooks > Science & Mathematics > Biology & Life Sciences > Biology’ as of June 30th, 2021. I excluded popular science books, exam preparation materials, as well as

other books from the same series (such as Campbell Biology Series) and by the same authors whose books were selected earlier. This had the advantage of serving as an independent criterion for the selection of books, to avoid the appearance of the selection of books containing the narrative that I am arguing they do. Table 1 lists the chosen textbooks.

Table 1 Biology textbooks used for the study

Book (henceforth referred as)	Full Citation	Amazon ranking (June 30th, 2021)
Campbell Biology	Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., & Reece, J. B. (2017). *Campbell Biology* 11th ed. New York, NY, USA: Pearson.	3
Biological Science	Freeman, S., Quillin, K., Allison, L, Black, M., Podgorski, G., Taylor, E. & Carmichael, J. (2019). *Biological science* 7th ed. New York, NY, USA: Pearson Education.	6
Miller and Levine Biology	Miller, K. R., & Levine, J. S. (2010). *Biology: On Level: Student Edition.* New York, NY, USA: Pearson.	19
Concepts of Biology	Fowler, S., Roush, R., Wise, J. (2013). *Concepts of Biology.* Ann Arbor, MI, USA: Xanedu Publishing.	21

The selected textbooks have a wide reach and are often prescribed at the university and advanced high school levels. Campbell Biology states that it has been translated in 19 languages and its different editions over the last three decades have been used by millions of college students worldwide. Campbell Biology series and Biological Science also feature as the recommended textbooks for various undergraduate institutes in India (including state and central universities and research institutions). Instructors at various colleges in India also use Openstax textbooks (the initiative that publishes open-licenced freely available books, such as Concepts of Biology used here) as the prescribed reading for their courses.

2.4.2 Interviews

I conducted 14 semistructured interviews of college students (either pursuing BSc or MSc). While the first 3 interviews were considered pilot interviews, I report the findings from the next 11 interviews. Out of them, most (9) students were studying B.Sc. while 2 were pursuing a master's degree. All interviews were audio recorded and transcribed for further analysis. I performed a deductive analysis of the interviews to map the themes that had emerged during the analysis of textbook discourse. I analysed the students' understanding of the functioning of the cell, as well as their conceptions regarding the structure of ecosystems. As with the analysis of textbook discourse, I paid attention to the metaphors that the students used, their word choices, the order in which they listed the cellular components. I also focussed on points where students were questioning or beginning to question the textbook narrative.

I also conducted semi-structured audio-recorded interviews with illustrators to understand their process of illustration and the motivations behind their aesthetic choices. In addition, data in the form of talks, writings and tweets by illustrators that shed light on their process were obtained. While some interviews were conducted in person, others were conducted through online platforms.

2.4.3 Illustrations

The narrative of evolutionary history is not learnt only through textbooks—prehistoric organisms such as dinosaurs are a large part of popular culture. Therefore, following the textual analysis of textbook representation, I performed a discourse analysis of scientific illustrations. To analyze the visualization of prehistoric life I chose the illustrations of iconic early twentieth-century paleoartist Charles R Knight. His art inspired generations of palaeontologists, biologists, as well as non-scientists, and continues to shape the public imagination (Berman, 2003; Kwon, 2019). In addition to the importance of Knight's work, there were several advantages to studying his illustrations. First, many illustrations are freely available online. Secondly, Charles Knight's illustrations, unlike textbook ones, depict prehistoric *scenes* in which organisms are shown behaving naturally in their natural habitat and the depicted behaviours could be studied as well. Admittedly, palaeontology has progressed much further since Charles Knight's illustrations, and there are recent artists who depict dinosaurs in non-traditional ways. Despite this, Charles Knight's images remain popular. I argue that the appeal of this imagery, in addition to the artistic brilliance of Knight, also lies in how they conform to our long-held beliefs regarding the 'ladder of life'.

2.5 Research questions

- What values are carried through representations in the biology textbooks?

This question changed into a specific set of questions once it became apparent that dominance hierarchy was a pervasive theme in the biological discourse.

- How does the textbook discourse on the cell construct a hierarchical functioning of the living cell? What does the analysis of word choices, grammatical structures and visual discourse reveal?
- How does textbook discourse on evolutionary history construct a hierarchical organisation of the living world? What does the analysis of textual features and visual discourse reveal?

2.6 Validity Concerns

Interpretation of text and visuals requires inference of their meaning, and this process involves the subjectivities of the researcher. Regmi (2017) explores how critical discourse analysis can ensure methodological rigour at the same time rejecting the positivist epistemologies regarding validity and objectivity. Regmi outlines three meanings associated with 'objectivity': a) the positivist ideal of being free from any subjective biases; b) being aware and reflexive of the subjectivities and biases; c) developing an "intersubjective consensus". While the epistemological paradigm in which this work is embedded in, radical constructionism, does not subscribe to objectivity in the first sense, I have strived to make my results objective in the second and third sense. Radical constructionism holds that objects of research and their linguistic representations co-constitute each other (Madill, Jordan, & Shirley, 2000). It thus makes no attempts to access the 'true' reality without any prior assumptions but focuses more on how natural and social reality invites particular representations and the representations shape the objects in a particular way.

For ensuring objectivity in the second sense, as Regmi (2017) suggests, I have employed textual empiricism, which borrows the quantitative methodologies and involves counting the number of words, passive sentences, pauses, and similar relevant features in the textual discourse. I have also chosen textbooks using an independent popularity criterion, and not

selected the ones which most starkly display the rhetoric I have identified. I have also looked for counterexamples and attempted to understand the contexts in which they emerged.

For objectivity in the third sense, I provide thick descriptions of textual and visual features of the discourse, so the reader may judge the validity of the findings. Guba (1981) also notes that thick descriptions are necessary for the transferability of the study. According to Madill, Jordan, and Shirley (2000), reader evaluation is an important quality criterion within the paradigm of radical constructionism, along with internal coherence and deviant case analysis. As Gee (2005) argues, convergence in findings from analysis of different features of text, using different tools and questions, also serves to validate the analysis. I, therefore, pursued different techniques to scrutinise the text, including the lexical features, grammatical features, as well as the analysis of visual modality.

For expert validation, I discussed my analysis with biologists teaching at the Indian Institute of Science Education and Research (IISER), Pune and the Indian Institute of Science (IISc), Bangalore.

Chapter 3. Critical discourse analysis of the textbook representation of the cell

A number of scholars have shown the prevalence of multiple metaphors in biological conceptions of the living cell. However, there is little research into unpacking these metaphors to understand their ideological implications for scientific knowledge and science education. In this paper, I perform a critical discourse analysis of the representation of the cell in introductory biology textbooks, particularly focusing on metaphors. This analysis reveals that a cell is portrayed as a centralised and hierarchical system, with the nucleus as the ‘control centre’ that provides ‘instructions’ to be executed by the cytoplasmic ‘machinery’. The vocabulary analysis shows that words like ‘information’, ‘instructions’, ‘command’, and ‘control’ are much more often used to describe the functioning of the nucleus. On the other

hand, words invoking societal manual labour, such as ‘manufacturing’, ‘producing’, ‘packaging’, ‘shipping’, ‘exporting’ and so on, are used to characterise the activities of the cytoplasm and the organelles. Further, when describing the ‘manual labour’ happening in the nucleus, the textbooks tend to distance the nucleus from this activity by using agentless passive voice. Following this textual analysis, I also demonstrate the centralized view of the cell mirroring in the textbook visuals and in college students’ conceptions regarding how the cell functions.

I then synthesise insights from experiments conducted in diverse fields of biology to show that control and ‘information’ are distributed across the cell rather than localised in the nucleus. Research from developmental biology makes a case for the ‘stores of information’ in the cytoplasm of the egg cell. Barbieri’s (2003) notion of ‘organic codes’ similarly maintains that the genetic code is not the only code in the cell. Further, the recent research in “organelle crosstalk” refutes the hierarchical and ‘assigned’ division of labour portrayed in the textbooks. Perplexingly, despite these strands of empirical research, textbooks have continued to portray the cell as a centralised system. I, therefore, attempt to understand the strong allure of the centralised metaphors by tracing their historical and cultural roots. I argue that their appeal lies in their congruence with our theoretical frameworks, gender ideologies, and social and political structures. Vienne (2018) shows that the microscopic observations of fertilisation in the early nineteenth century had shown that the egg is much larger than the sperm suggesting the maternal contribution to be greater in the progeny. However, an equal contribution of the two sexes was still possible if there was a component, equal in size in both gametes, which was responsible for the hereditary characteristics. Researchers in the late nineteenth century, who had observed the fusion of male and female nuclei under the microscope during the process of fertilisation, found just such a candidate in the nucleus. The view that the nucleus alone was responsible for heredity gained acceptance during this time

(Vienne, 2018). Based on the history of twentieth-century biology, Keller (1997) has similarly argued that the gendering of cellular components—the cytoplasm as the equivalent of the egg, and the nucleus that of the sperm—led to the emphasis on the nucleus. Keller (2003) further shows the various discourses during different decades, from the 'discourse of gene action' to the 'discourse of gene activation' maintained the primacy of the gene using various rhetorical shifts. Manning's (1985) account of the American embryologist E. E. Just's work and Gilbert's (1988) analysis present insights into how the social positioning of scientists can influence the way they relate to the natural systems under study. Just was a Black scientist active in the early twentieth century United States. Just (1939) astutely observes that the peripheral cytoplasm is capable of "highly active structural changes portray[ing] self-regulation and self-differentiation" (p. 9) that "has been subordinated as though it be a mere protective and nutritive shell" (p. 8) by the gene-centric view of development. Just's belief in self-regulation of the cytoplasm and his perspective of the nucleus (as the proxy for the government) as imposing "obstacles" (instead of "instructions" as held by the dominant metaphors) raises the possibility that his social positioning afforded him a different perspective of the cell. This also suggests that the perspectives and social experiences of the dominant groups—historically overwhelmingly upper-class White men, who might have identified with the nucleus that is giving instructions—might have led to the nucleus-centric view being favoured over others. In light of Just's metaphor, it becomes clear how the dominant metaphor of "the cell as a factory" carries the "hidden power" (Fairclough, 2001) of dominant societal classes. It parallels and naturalises the societal hierarchy of executives over the toiling masses. The work of executives is often assumed to need knowledge and skills and hence considered more valuable, while the work on the factory floor is considered merely 'executing the instructions', thereby undervaluing the worth of manual work, as well as the wealth of knowledge and skills needed in performing it. This

shows how the scientific discourse, otherwise perceived as objective and value-neutral, can serve as a 'Trojan horse' for the ideology of centralization and dominance hierarchy. I conclude this chapter by highlighting the need to explore newer ways of understanding and describing the cell, a dynamic and self-organising structure that functions without explicit instructions and coercive control.

Chapter 4. Critical discourse analysis of the textbook representation of evolution

The ranking of living beings in hierarchical order has persisted across different cultures and philosophies for millennia. Aristotle's 'ladder of life' and the mediaeval notion of the 'great chain of being' categorised organisms into 'higher' and 'lower' forms. The German biologist Ernst Haeckel's 'tree of life' revisited the 'ladder of life' through the lens of evolution. He believed evolutionary progress led to 'higher' organisms from the "primitive" and "lower" ones. While this idea was dominant in biology until the nineteenth century, modern biological thinking holds that "evolution is not goal oriented" (Campbell Biology, p. 545) and drawing a linear path from the fossil record "creates the illusion of a progressive trend" (Campbell Biology, p. 447). Despite this, I show in this chapter, Haeckel's tree of life persists in subtle ways in modern biology textbooks. This is evident in how the Mesozoic era is named 'the Age of Reptiles', while the present Cenozoic era is called 'the Age of Mammals'. Textbooks suggest a linear narrative of evolutionary history, with successive 'rise' of amphibians, reptiles, and mammals in accordance with the 'ladder of life'. Counterexamples to this narrative of history, such as the 'dominance' of ancient relatives of mammals (non-mammalian synapsids) of the time before and during the 'Age of Reptiles', are omitted or downplayed in the texts. While the Permian-Triassic (P-T) extinction and the extinction of large proto-mammals and "rise" of dinosaurs is described only cursorily, the textbooks

describe the Cretaceous-Paleogene (K-Pg), which led to the extinction of non-avian dinosaurs and “rise” of mammals is described in much more detail.

Further, textbook descriptions subtly construct dinosaurs as monsters. This indicates that the “proto-idea” of dinosaurs as “monstrous beasts” survives in the textbook representation. The narrative of the Cretaceous-Paleogene (K-Pg) extinction, for instance, highlights that monstrous and gigantic beasts went extinct after the asteroid impact which was braved by small creatures forced to live a nocturnal life until then. These small creatures, we are then told, later prospered and they now dominate the earth. This representation invokes the fairy tale of ‘David and Goliath’, in which the ‘ungodly’ giant was defeated by the small but clever David. The association between monsters and dinosaurs, but not large animals in general, is partly ideological. In human history, military campaigns have often begun by labelling the civilizations that they attacked as monsters, savages, and “barbarians”. Fairy tales, too, often end with monsters getting killed. This connotation makes K-Pg extinction appear a rightful and inevitable course of history, as against historical accidents that all mass extinctions have been.

Since the narrative of evolutionary history is also constructed through popular culture, I also analyse the visualisation of prehistoric life. Using the visual descriptions of colours, postures, and behaviour of the depicted prehistoric organisms, I show how subtle rhetorical choices uphold the ‘ladder of life’. Through the colour choices, prehistoric reptiles are portrayed as similar to present-day reptiles, in turn constructing the present-day reptiles as ‘vestiges of ancient past’. The prehistoric reptiles are portrayed as aggressive beasts, while the prehistoric mammals are more often shown as social creatures but less often as aggressive creatures. Through various rhetorical manoeuvres, the ancient mammalian relatives are suggested to be reptile-like reinforcing the primitiveness of reptiles in comparison to mammals. This

visualization reinforces the ladder of life and casts present-day reptiles as vestiges of the ancient past while suggesting that mammals are ‘advanced’.

More insidiously, this implicit conception of the ‘ladder of life’ also shapes visual representations such as the ecological pyramid, which depicts interrelationships between the present day life-forms. I show that the ecological pyramid performs several rhetorical manoeuvres to impose a dominance hierarchy on an ecosystem. The British Zoologist Charles Elton (1927), who put forth the concept of ecological pyramid in his book Animal Ecology, began that particular section with the following quotation: " One hill cannot shelter two tigers.” (p. 68). Elton then went on to describe how predators have a territory that takes care of their food requirements. Instead of representing ecological relationships with a simple histogram, Elton chose to perform a series of rhetorical moves to represent the ecological relationships in the form of a “pyramid”. The producers at the bottom, living on the territory “ruled” by predators invokes the feudal hierarchy between land-owning noblemen and producer peasants.

More instructive is the case of organisms usually not depicted in the textbook diagrams of the ecological pyramid. Microbes, parasites, and decomposers are often labelled outside the pyramid but not included within it. Similarly, humans are rarely included in the pyramid. I argue that this is because of the dissonance between the would-be place of humans and microbes in the pyramid, and their perceived place according to the ‘ladder of life’. Microbes would have to be shown *above* the current apex, i.e. above the predators in the pyramid, but they are at the lowermost rung in the ladder. Humans, the topmost on the ladder, would occupy the middle position in the pyramid. Rather than conceding the right positions for these organisms according to the stated rules of the pyramid representations, their depiction is avoided entirely. The hierarchical representations of the ecological pyramid and ladder of life

interact in a complex manner to create a stronger sense of dominance hierarchy. As I show in the textbook analysis, the narrative of evolutionary history suggests that the organisms at the top of the pyramid rule the earth in that particular period. The omission of the diversity of ancient mammalian relatives gives a false impression that reptiles were at the top of the pyramid when mammals had not originated or were just emerging. It also suggests that since the 'advanced' mammals have originated, they have taken their rightful place in the pyramid.

Following the discourse analysis, I attempt to understand the appeal that the hierarchical view of the natural world possesses and delineate the often-used fairy tale tropes and enduring "proto-ideas" that the view carries. The hierarchical view implicitly justifies 'The Age of Mammals', 'Anthropocene' and the place of humans on 'top' of the natural world. I show that the narrative of evolutionary history projects the masculine assumptions of conquests and dominance onto the natural world. This evolutionary history focuses on the 'rulers' of each era with the assumption that these organisms *represent* the particular eras. The hierarchical view of nature also resonates and naturalizes social inequalities by portraying the "powerful" consumers on the top and "producers" at the bottom. The linear view of evolution and the hierarchical view of the natural world, in addition to being covertly ideology-laden, limits the true understanding of diversity and richness of life.

Chapter 5. Conclusions and Future Directions

This thesis shows that Dominance hierarchy as a hidden value pervades the biological discourse at various levels of analysis. Not only topics that are quite obviously politically charged, such as genetic determinism and biological basis for sex or race, but seemingly innocent scientific concepts are also value-laden. As I showed in Chapter 3, through the cell as a factory metaphor, the societal hierarchy between mental and manual labour is projected

onto the cell, making it appear ‘natural’. While the hierarchy of capitalist society is projected onto the living cell, the feudal hierarchy becomes apparent in the discourse on ecosystems and evolution. The entrenched idea of the ‘ladder of life’ influences the narrative of evolutionary history as well as relationships between present-day organisms in the representation of the ecological pyramid.

In the final chapter, I discuss the implications for science education research, for the practice of science education, and for the practice of science. Given the examples of the cultural construction of scientific knowledge, I argue that textbook writers and science educators should be mindful that scientific terms and concepts do not transparently capture natural phenomena under study, but are often loaded with societal and cultural references. The endeavours such as feminist epistemology and science studies, which identify and challenge the hidden ideologies in science, will not be completed until they are able to reach, alter, and enrich the textbook discourse.

This thesis also makes a case that Biology Education Research (BER) would be enriched by insights from science studies. BER focuses on improving teaching or student learning, but as I have argued, the ideologies can be inherent in the *concepts* of biology. BER should therefore expand its aims to study not just how students learn concepts but also how they acquire ideologies through scientific content. BER can also probe the teaching practices to understand how one can engage with values while teaching biology. This could lead to important contributions.

The present analysis also offers implications for science education that would impact the practice of science. Science educators (Allchin, 2014; Bansal, 2018) have advocated for incorporating critical studies of science and the historical context of scientific discoveries in science teaching. Such critical and feminist pedagogy for science (such as practiced by Mayberry and Rees, 1997) can reveal the cultural construction of knowledge to would-be

scientists. Evolutionary biologist Gowaty (2003) has argued that being a feminist biologist has improved her experimental designs. She also contends that being reflexive of their biases can help scientists set up experimental controls and ask different questions. Teaching the historical and cultural context of knowledge generation at the undergraduate level can positively impact the practice of science as well.

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