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Representation of Learning Outcomes Stipulated by the Intended Curriculum in Four Series of Chemistry Textbooks: Based on Legitimation Code Theory

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Abstract

Intellectual demands of learning outcomes in the intended curriculum have always been a concern across the field of science education. In particular, the representation of those learning outcomes stipulated by the intended curriculum in science textbooks has become a big issue for both science curriculum studies and science teaching practice. To address this issue, the concepts of semantic gravity (SG) and semantic density (SD), as part of the dimension of Semantics from Legitimation Code Theory (LCT), were employed in this study with the purpose of examining the degrees of abstraction and complexity of chemical knowledge under the topic "common substances" in four series of chemistry textbooks, which were compiled in compliance with the national chemistry curriculum of the compulsory education (Grades 1–9) in China. Based on the principles of LCT (Semantics), a new scheme for differentiating the strengths of SG and SD was developed in the current study to analyze the representation of 34 knowledge points in the four series of chemistry textbooks. Results show that these knowledge points are embodied with less complexity and avoid more abstraction in the four series of chemistry textbooks. Specifically, it was found that the overwhelming majority of the knowledge points are represented with strong semantic gravity and weak semantic density. Uniqueness was also identified with individual series of chemistry textbooks. The implications of the results of this study are discussed for the effective representation of science (chemistry) knowledge in textbooks.

Keywords Science textbooks · Intended science curriculum · Learning outcomes · Legitimation Code Theory (LCT) · Semantics · Semantic density (SD) · Semantic gravity (SG)

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Introduction

In recent decades, standards-based reform has played a dominating role in science education landscape across the world (DeBoer, 2011; Hamilton et al., 2008). One prominent feature of standards-based science curricula is that scientific knowledge and skills that students are expected to know and be able to do are usually presented as learning outcomes (LOs) in the national curriculum, which reflects the vision or basic philosophy that education authorities adhere to (Thorolfsson et al., 2012). An emerging line of research in recent years is to address the issue of intellectual demands of learning outcomes stipulated in the national science curricula on the basis of the revised Bloom's Taxonomy (e.g. Elmas et al., 2020; Lee 2015; Lee et al., 2017; Lee & Tan, 2018). Later on, Lee and Wan (2022; Wei & Ou, 2019) interrogated an alternative form of intellectual demands presented in intended science curricula, i.e. the abstraction and complexity of LOs by taking semantic gravity (SG) and semantic density (SD) as an analytical tool, two key concepts in Semantics, a dimension of the Legitimation Code Theory (LCT). While recognizing the necessity of investigating the abstraction and complexity of LOs stipulated in the intended science curriculum, it is also important to explore the same issue at the level of textbooks.

As we know, textbooks are not only a bridge between the intended curriculum and implemented curriculum but also an essential resource for science teaching and learning (Vojíř & Rusek, 2019). Science textbooks often serve as the primary organizer of subject matter that students are expected to master and they are usually taken as the major curriculum resource supporting teachers' preparation for classes (Rusek & Vojíř, 2019). However, the same scientific content could be elaborated on in different versions of textbooks in different ways. The lack of consistency in presenting scientific knowledge across different versions of textbooks may result in some negative outcomes. For students, it could make them develop misconceptions or experience confusion, which, in turn, hinder them from in-depth understanding of the subject matter. This, in effect, may have a negative impact on students' academic achievement (Hadar, 2017; Schmidt et al., 2001; Sievert et al., 2019). For science teachers, when encountering different versions of textbooks written by diverse author groups and published by various presses, they have difficulty understanding of the scope and depth of scientific topics prescribed in the intended science curriculum (Chen & Wei, 2015).

According to LCT, textbooks can be seen as a kind of knowledge practice that specifies what knowledge is valued and legitimate in the community of science teaching (Maton, 2020). When attempting to embody LOs stipulated in the intended curriculum into textbooks, textbook authors, either consciously or unconsciously, need to consider scientific knowledge contained in the LOs, commonsense knowledge, and educational knowledge as well within socio-cultural practices. For teachers and students, the main stakeholders of textbooks, the embodiment of LOs in textbooks primarily means how intellectually demanding they are. As an analytical tool, LCT (Semantics) can be used in exploring knowledge abstraction and complexity because it "enables knowledge practices to be seen, their organizing principles to be conceptualized, and their effects to be explored" (Maton, 2014, pp.2–3). Exploring intellectual demands of science knowledge at the level of textbooks in the view of SG and SD would be helpful to uncover the nature of scientific knowledge presented in science textbooks and eventually beneficial for the effective implementation of the intended science curriculum.

Based on the principles of Semantics/LCT, a new scheme of differentiating the strengths of SG and SD was developed in the present study to understand the abstraction and complexity of chemical knowledge in four popular series of chemistry textbooks, which were compiled in compliance with the national chemistry curriculum standards of the compulsory education (NCCS) (MoE 2022). The purpose of this study is to examine how SG and SD provide insights into the issue of abstraction and complexity in chemistry textbooks in regard to those LOs stipulated in the intended chemistry curriculum (MoE 2022). The research questions are raised as follows:

1. What are the features of learning outcomes prescribed in the 2022 NCCS in the four series of chemistry textbooks with respect to semantic gravity (abstraction) and semantic density (complexity)?
2. What are the similarities and differences of semantic gravity (SG) of learning outcomes prescribed in the 2022 NCCS among the four series of chemistry textbooks?
3. What are the similarities and differences of semantic density (SD) of learning outcomes prescribed in the 2022 NCCS among the four series of chemistry textbooks?

Legitimation Code Theory

Legitimation code theory (LCT) is a framework that encompasses multiple dimensions and is inspired by the research of Bernstein (2000), who investigated the production of knowledge in academic disciplines through the analysis of various forms of discourse. LCT extends Bernstein's work by exploring how knowledge is organized and transmitted across various social practices, including education, science, sociology, and linguistics. By examining the underlying principles that generate discourses, knowledge structures, curriculum structures, and forms of learning, LCT provides insights into how knowledge is legitimized and how it can be organized to promote cumulative learning (Maton, 2009). In the field of education, for instance, LCT can be employed to examine the language used in textbooks, a kind of knowledge practice, to determine if it is appropriate and conducive to cumulative learning (e.g. Kelly-Laubscher & Luckett, 2016). Five dimensions (specialization, semantics, autonomy, temporality, and density) are involved in this framework (Maton, 2014), of which the dimension of Semantics is what we focused on in this study.

Semantics, a dimension of LCT, constitutes the constructs of semantic gravity (SG) and semantic density (SD). According to Maton (2013), all meanings relate to a context of some kind; semantic gravity conceptualizes how much they depend on that context to make sense (p.11). Strong semantic gravity (SG+) means the meaning is generated heavily relying on its context, whereas weak semantic gravity (SG-) means the meaning is generated more independently of its context. When we say that a concept or meaning is abstract, it normally refers to it being a prototype that aggregates normative features associated with it (Lee & Wan, 2022). In this sense, the degree of abstraction can be assessed by the strength of semantic gravity: when semantic gravity is stronger, meaning is more closely related to its context; when it is weaker, meaning is less dependent on its context.

The degree of complexity is termed semantic density which refers to the amount of meaning condensed in any given practice, such as words, phrases, or symbols that are used to convey meaning within a given context (Maton, 2014). When the semantic density is strong (SD+), there is more meaning condensed within practices. Conversely, when the semantic density is weak (SD-), there is less meaning condensed within practices. It was suggested that all knowledge practices can be characterized by both semantic gravity and semantic density and what differs are their strengths (Maton, 2020). They may strengthen or weaken independently to create semantic codes (e.g., SD+/SD-, SG+/SD-). Given that semantic gravity and semantic density trace a continuum of strengths, they provide an infinite capacity for gradation (Georgiou et al., 2014). These continua of strengths can be presented on a Cartesian plane, namely the semantic plane (Fig. 1). By combining these codes, four possible modalities can be produced: Rhizomatic codes (SG-, SD+), Rarefied codes (SG-, SD-), Prosaic codes (SG+, SD-), and Worldly codes (SG+, SD+) (Fig. 1). The changes in semantic gravity and semantic density are fundamentally independent. To illustrate, if a concept (knowledge point) demands specific understanding within a particular context, the meanings condensed may not necessarily be fewer.

These modalities can be used to determine what is valued as legitimate practice (Kelly-Laubscher & Luckett, 2016). For example, prevalence of each of the codes discussed above in a chemistry textbook reflects, to some extent, whether the language the textbook tends to use is abstract or concrete, simple or complex. The choice of which code to employ is determined by the context rather than adhering to a hierarchy where certain forms of knowledge, such as theoretical or practical knowledge, are assumed to hold more dominance than others. It is well known that educational controversies have always been dominated by a recurring debate between "theoretical" and "practical" knowledge (Maton, 2020). Under this situation, this framework draws attention to the fact that knowledge should not be dominated by the dichotomy between theoretical (quadrant 1: SD+, SG-) and practical (quadrant 3: SD-, SG+) forms that commonly appear in many pedagogical

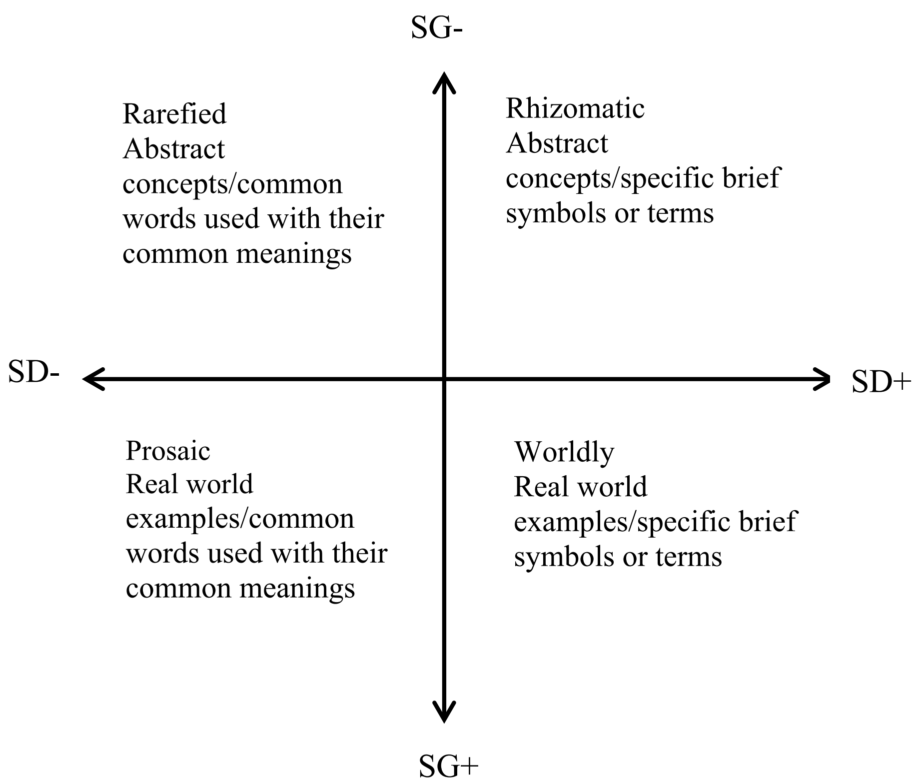

Fig. 1 Semantic plane (Adapted from Maton, 2016, p.16)

discourses (Maton, 2013). Instead, this framework provides a space for educators to see what has been previously hidden by thinking in terms of dichotomies by moving beyond just valuing either theoretical knowledge (quadrant 1) or practical knowledge (quadrant 3) and exploring the potential of integrating "rarefied" (quadrant 2) and "worldly" ways of knowing (quadrant 4) in science education (Lee and Wan, 2022; Maton, 2020). LCT (Semantics) has been applied to a range of different practices in recent research in the field of science education. For example, this framework was used to examine the semantic patterns of many kinds of written and oral discourses, such as high-stakes chemistry examination papers (Rootman-le Grange & Blackie, 2018), biology textbooks (Kelly-Laubscher & Luckett, 2016), science learning outcomes (Lee and Wan, 2022), and science teachers' discourses (Cranwell & Whiteside, 2020; Dankenbring et al., 2024; Macnaught et al., 2013). The focus of semantics on social practice enables it to identify the ways in which knowledge is legitimized through the use of specific language and symbols. This is particularly relevant for analyzing textbooks, which remain an important influence in the classroom. Based on these considerations, semantics is adopted as a suitable tool to analyze textbooks in this study.

Application of LCT in this Study

As a dimension of the LCT framework, semantics provides a theoretical basis for analyzing a range of practices, such as language and dance (Georgiou et al., 2014). Given that different practices may have unique features and characteristics, the analytical tools of semantics may not be immediately applicable or relevant to all contexts. Hence, effort must be invested in constructing "translation devices" or typologies with multiple levels that can be applied in a certain context to analyze objects and data (Maton, 2020). In other words, it is important to customize the semantic codes to meet particular research needs without violating its principles when conducting a study using this method. For the purposes of this study, the meaning of semantic gravity and semantic density should be discussed in the context of chemistry textbooks.

In chemistry textbooks, the content is generated in detail to present the knowledge points, which are contained in the learning outcomes stipulated in the chemistry curriculum, and they are usually in the form of a noun or noun phrase. The knowledge points are usually represented in text on a hierarchical knowledge structure, where upper level knowledge builds on lower level knowledge. However, a knowledge point might be embodied with different degrees of abstraction and complexity in different versions of textbooks. On one hand, a knowledge point might be expanded to hierarchically different levels in various versions of textbooks. For example, in one textbook, it may be addressed at one level (the same with that it appears in the intended chemistry curriculum); however, in another textbook, it may be extended to multiple levels, which expands the original meaning of the knowledge point stipulated in the intended chemistry curriculum. In the latter case, according to Matruglio (2022), the semantic gravity (SG) is weaker as its meanings are less tied to its context. Thus, in this study, the number of the levels to which a certain knowledge point is expanded by the textbook serves as the basis for assessing semantic gravity of a knowledge point: the more levels of a knowledge point extended by the textbook, the greater degree of abstraction of the knowledge point. On the other hand, the same knowledge point might be elaborated in different details in various series of textbooks: some textbooks may provide extensive elaboration on it with multiple detailed messages about this knowledge point while others may just mention the academic terms very briefly. In this study, the semantic density of a knowledge point, which serves as an indicator of complexity, is assessed on the basis of the degree of detail elucidated for the knowledge point in the textbook: the more messages detailed in the textbook, indicating a greater degree of complexity of the knowledge point.

The knowledge point of "properties of concentrated sulfuric acid" is used to illustrate the above ideas. One textbook (A) provides a detailed explanation of sulfuric acid properties such as color, state, odor, corrosiveness, and the product of its corrosion as well. Another textbook (B) describes it briefly, such as just mentioning its corrosiveness. Thus, this knowledge point has relatively stronger semantic density in textbook A because it condenses much more messages related to the knowledge point than in textbook B. Meanwhile, this knowledge point has relatively weaker semantic gravity in textbook A since the messages within this knowledge point are organized at two levels (one is the color, state, odor, the corrosiveness and the other is the product of its corrosion), which exceeds the level of messages found in textbook B. The criteria for assessing semantic gravity and semantic density of the knowledge points in chemistry textbooks will be discussed in the section of methodology. As suggested by some scholars (e.g. Rootman-le Grange & Blackie, 2018; Steenkamp et al., 2021), to achieve a more nuanced representation of semantic codes, the scales of SG and SD strengths are refined by extending from SG+/- and SD+/- to SG++/--and SD++/-—respectively in this study. Thus, the four code combinations can be extended to 16 ones, which is shown in Fig. 2.

Methodology

The aim of content analysis is to discover and describe the phenomena under consideration by organizing large volumes of words into fewer content categories based on explicit encoding rules (Stemler, 2001). This research method was adopted in this study to explore the degree of abstraction and complexity of knowledge in chemistry textbooks by identifying and describing how learning outcomes in the intended chemistry curriculum are represented in different chemistry textbooks. Specifically, based on the

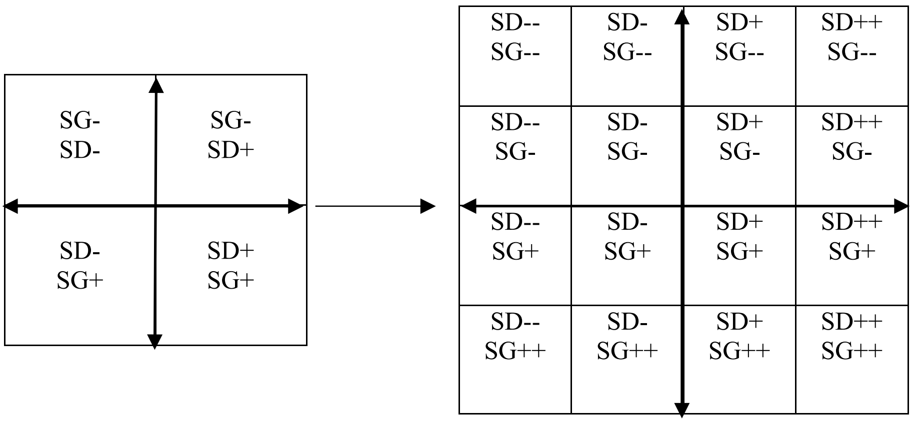

Fig. 2 Semantic codes

concepts of semantic gravity and semantic density, the study was conducted to provide evidence to the three research questions raised earlier.

Data Sources

In China, for a given school subject, national curriculum standards form the basis for designing school curricula and textbooks (Wei, 2019). These curriculum standards are set and adjusted periodically to ensure they are up-to-date. For this reason, we targeted the 2022 NCCS (MoE 2022). This official document outlines what should be taught (curriculum content), how knowledge should be taught (curriculum implementation), and how students' performance should be evaluated (assessment) in chemistry teaching and learning (MoE 2022). The "curriculum content" is composed of five themes, they are: (1) "Scientific inquiry and chemistry experiment", (2) "Properties and applications of substance", (3) "Composition and structure of substance", (4) "Chemical changes of substance", and (5) "Chemistry and society" (MoE 2022). Under each theme, a cluster of learning outcomes are stipulated. For the purpose of this study, attention was devoted to the knowledge-oriented themes (i.e. the second, third, and fourth themes) rather than the skills-oriented theme (i.e. the first theme) or emotions-oriented theme (i.e. the fifth theme). Compared to other knowledge-oriented themes, which are always presented in a scattered way in textbooks, the second theme, "Properties and applications of substances", is usually presented in a rather intensive manner, making it easier to recognize and compare the embodiment of knowledge points in various series of chemistry textbooks. Under this theme, the topic of "common substances" describes the essential concepts and knowledge of common substances in the world that students are expected to learn. For this reason, we targeted the "common substances" topic in the 2022 NCCS in the present study.

In most cases, a learning outcome consists of a verb and a couple of nouns or noun phrases, which represent the main ideas that a student should know and learn after instruction (MoE, 2022). A learning outcome is taken from the 2022 NCCS as an example: *"Be able to explain the properties and applications of oxygen and carbon dioxide with examples*" (MoE 2022, p. 18). In this learning outcome, four knowledge points can be identified: the properties of oxygen, the applications of oxygen, the properties of dioxide, and the applications of dioxide. In the 2022 NCCS, the topic "common substances" is composed of four categories of chemical knowledge: "Air, oxygen, and carbon dioxide", "Water and solutions", "Metals and metallic minerals", and "Common acids, bases, and salts" (MoE 2022), from which a total of 34 knowledge points were identified (see Table 1).

In China, for the subject of chemistry offered in the stage of junior secondary education (7–9 grades), there are several series of textbooks produced by various publishers. In this study, we focused on four series of chemistry textbooks, which are mostly adopted in junior secondary schools across the country. They were those respectively published by the People Education Press (PEP), Shanghai Education Press (SHEP), Guangdong Education Press (GDEP), and Shandong Education Press (SDEP). The relevant chapters of the four series of chemistry textbooks are shown in Table 2. In these textbooks, chemical knowledge is presented in texts to elaborate on those learning outcomes stipulated in the 2022 NCCS. Thus, these texts in the four series of chemistry textbooks made up the data sources for this study.

Table 1 Knowledge points under the topic of "common substances" in the theme of "Properties and applications of substance" (adapted from MoE, 2022, pp.18–20)

Topic/Theme	Categories	Knowledge points	Count
Common Substances/ Properties and Applications of Substance	Air, oxygen, carbon dioxide	Main components of air; Properties of oxygen; Properties of carbon dioxide; The properties and applications of substances (except oxygen and carbon dioxide); Oxygen cycle in nature; Carbon cycle in nature	6
	Water and solutions	Composition of water; Common methods of water purification; Dissolution phenomenon; Crystallization phenomenon; Solution is composed of solute and solvent; Solution has homogeneity and stability; Saturated solution; solubility; Solute mass fraction	9
	Metals and metallic minerals	Most metals exist in nature as metallic minerals; Common physical properties of metals; Main chemical properties of metals; The reactivity series of metals; Alloys; Common methods to prevent corrosion of metals	6
	Common acids, bases, and salts	The main properties and uses of hydrochloric acid; The main properties and uses of sulfuric acid; The main properties and uses of sodium hydroxide; The main properties and uses of calcium hydroxide; The main properties and uses of other acids; The main properties and uses of other bases; The basic method of testing the acidity and alkalinity of solutions; The effect of acidity and alkalinity on human health and crop growth; The application of salt in daily life; The application of soda ash in daily life; Application of baking soda in daily life; Application of calcium carbonate in daily life; Common chemical fertilizers	13

Table 2 Relevant chapters of the four series of chemistry textbooks under study

Publisher	Chapters involved	Authors/Editors
PEP	Book 1: 2. The air around us 4. Water in nature 6. Carbon and oxides of carbon 7. Fuels and their uses Book 2: 8. Metals and metal materials 9. Solution 10. Acids and bases 11. Salts and chemical fertilizers 12. Chemistry and life	Wang & Zheng (2022)
SHEP	Book1: 2. Chemicals around us 4. Chemical changes 5. Extraction and uses of metals Book 2: 6. Dissolution 7. Widely Used Acids, Bases, and Salts 9. Chemistry and social development	Wang & Wang (2022)
GDEP	Book 1: 2.Air, Formation of substances 3.Oxygen: Life sustaining gas 4.Water: The origin of life 5.Fuels Book 2: 6.Metals 7.Solutions 8.Common acids, bases and salts	Jiang (2022)
SDEP	Book 1: 2.The secrets of water 4.The air around us 6.Combustion and Fuels Book 2: 1.Solutions 2.Common acids and bases 3.Chemicals in the sea 4.Metals 6.Chemistry and social development	Bi and Lu (2022)

Criteria for Differentiating the Strengths of SG and SD Codes

To achieve the purpose of the current study, a crucial task was to establish criteria to differentiate the strengths of SG and SD codes. As discussed earlier, for semantic gravity (SG), there also four codes: SG–, SG-, SG+, SG++; for semantic density (SD), there are four codes: SD–, SD-, SD+, SD++. In order to differentiate them, criteria were developed on the basis of preliminary analysis (see Table 3).

As mentioned earlier, semantic gravity (SG) is defined as the extent to which a certain knowledge point is expanded by the textbook under study. It can be assessed by the number of the levels that the messages involved in the knowledge point are deployed in text. As the hierarchical sequence of the messages progresses, it becomes inevitable for the knowledge point to be less dependent on contexts; and thus, the semantic

Table 3 Criteria for differentiating the strengths of SG and SD codes

SG–	**SG-**	**SG +**	**SG + +**
4 levels or above messages	3 levels of messages	2 levels of messages	1 level of messages
SD–	**SD-**	**SD +**	**SD + +**
1–10 messages	11–20 messages	21–30 messages	above 30 messages

gravity is weaker. As we found in the preliminary analysis, the messages involved in a knowledge point can be deployed at one to four or even more levels in texts. Thus, it was decided that a knowledge point which is extended with 4 or more levels was coded as SG– (weaker semantic gravity), 3 levels is coded as SG- (weak semantic gravity), 2 levels is coded as SG + (strong semantic gravity), and 1 level is coded as SG + + (stronger semantic gravity) (see Table 3).

Semantic density (SD) is defined as the degree of detail of a certain knowledge point embodied in the textbook under study, which indicates how complex the representation of the knowledge point is. In this study, the degree of semantic density was assessed by the number of messages related to the knowledge point presented in chemistry textbooks. As shown in preliminary analysis, some knowledge points were addressed in great detail, with up to 40 messages involved in textbooks, while others were not addressed at all. Thus, it was decided the strength of SD of a knowledge point is determined by the number of messages addressed in texts: 1–10 messages, termed as SD– (weaker semantic density); 11–20 messages, termed as SD- (weak semantic density); 21–30 messages, termed as SD + (strong semantic density); more than 30 messages, termed as SD + + (stronger semantic density) (see Table 3).

The execution of the criteria can be illustrated by an example which represents the knowledge point of "properties of carbon dioxide" in Book 1 published by PEP (p. 120):

> *Carbon dioxide reacts with water to form carbonic acid **[message 1]**; the chemical equation is* $H_2O+CO_2 \rightleftharpoons H_2CO_3$ *[**message 2**]*
> *Carbonic acid can turn purple litmus solution red **[message 3]**.*
> *Carbonic acid is an unstable molecule **[message 4]**. It can easily decomposes into carbon dioxide and water **[message 5]**; the chemical equation is* $H_2CO_3 \rightleftharpoons H_2O+CO_2$ ***[message 6]***
> *As the carbonic acid decomposes, so the red litmus solution turns purple again... **[message 7]***

As shown above, the knowledge point of "properties of carbon dioxide" contains 7 messages. Thus, according to Table 3, the semantic density of this knowledge point is SD–.

In order to assess semantic gravity of this knowledge point, it is necessary to see how it is expanded in texts. The logical sequence of the messages involved is visualized in Fig. 3.

As shown in Fig. 3, the 7 messages are organized at three levels: the first level is reaction with water to form carbonic acid and balanced equation; the second is the properties of easy decomposition and discoloration of litmus; and the third level is the product of decomposition, balanced equation, and restoration of color of litmus solution. Thus, according to Table 3, the semantic gravity of this knowledge point is SG-.

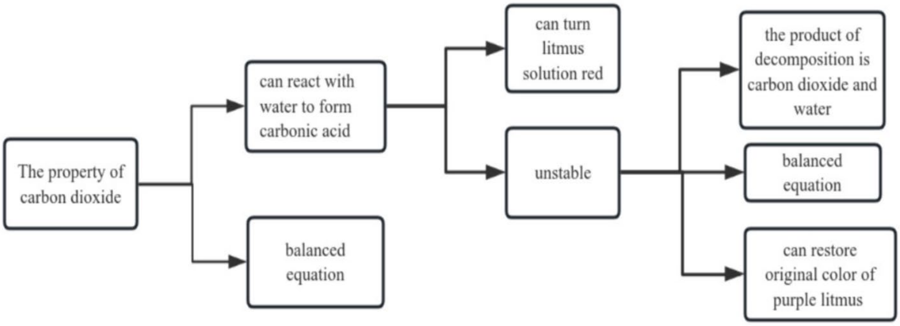

Fig. 3 The logical sequence of messages related to the property of carbon dioxide

Coding Process

A pilot study was conducted to determine the reliability of the criteria described above. The pilot study involved two coders, who were the first authors of this article. The two coders independently coded the 6 knowledge points under the category of “Air, oxygen, and carbon dioxide” in the chemistry textbook published by PEP to determine the level of agreement in their coding decisions. The coding decisions made by each coder were then compared, and the level of agreement between them was measured with a high level of agreement with 90% consensus which indicated the accuracy and reliability of the criteria. Based on the findings of the pilot study, we determined that the criteria was reliable and suitable for the subsequent analysis. To minimize the bias and ensure the reliability of the data, two authors independently coded the eight chemistry textbooks in the next stage. In cases where differences in coding decisions arose during the main coding stage, inter-coder discussions were conducted among the team members. These discussions aimed to resolve any discrepancies and reach a consensus on the coding decisions. It is important to note that the chemistry textbooks analyzed in this study were written in Chinese and coded prior to being translated into English. An English expert was consulted to ensure accuracy of the translation.

Results

The Features of Semantic Plane of “Common Substances” in Chemistry Textbooks

It should be noted that the 34 knowledge points in the four series of chemistry under study textbooks should have yielded 136 times of coding, but only 129 times of coding were ultimately generated, implying some of knowledge points are not addressed by any textbook at all. The 129 times of coding are presented in the extended semantic plane in Table 4 for the knowledge points under the topic “common substances” prescribed in the 2022 NCCS in the four series of chemistry textbooks. In Table 4, the data in each coding area includes the frequency of occurrence of that code combination and its percentage. The right-most column and the bottom row of Table 4 present the total frequency and percentage of each code in the semantic gravity and semantic density dimensions, respectively.

Table 4 The semantic plane of 34 knowledge points in the four series of chemistry textbooks

						Total (SG)
	0 (SG--, SD--)	**3** 2.32% (SG--, SD-)	**SG--**	**6** 4.65% (SG--, SD+)	**3** 2.32% (SG--, SD++)	**12** 9.30% (SG--)
	9 6.98% (SG-, SD--)	**16** 12.40% (SG-, SD-)	**SG-**	**11** 8.83% (SG-, SD+)	**2** 1.55% (SG-, SD++)	**38** 29.46% (SG-)
	SD--	**SD-**		**SD+**	**SD++**	
	30 23.26% (SG+, SD--)	**17** 13.18% (SG+, SD-)	**SG+**	**10** 7.75% (SG+, SD+)	**0** (SG+, SD++)	**57** 44.18% (SG+)
	21 16.27% (SG++, SD--)	**1** 3.45% (SG++, SD-)	**SG++**	**0** (SG++, SD+)	**0** (SG++, SD++)	**22** 17.05% (SG++)
Total (SD)	**60** 46.51% (SD--)	**36** 27.91% (SD-)		**27** 20.93% (SD+)	**5** 3.88% (SD++)	**129** 100%

Some overall features regarding the semantic plane for the 34 knowledge points of "common substances" in the four series of textbooks can be identified. First of all, as demonstrated in Table 4, data are available only for 12 of the 16 coding areas. There is an absence in some coding areas in the semantic plane, including (SG + +, SD +) (SG + +, SD + +) (SG +, SD + +) (SG–, SD–). Namely, the knowledge points have never been elaborated on or represented in either a specific (SG +; SG + +) or complex (SD +; SD + +) way in textbooks; and they have never been explained in the code combination of lower semantic gravity (SG–) and lower semantic gravity (SD–). Second, the percentage of coding combination (SG +, SD–) is the largest, followed by (SG + +, SD–) and (SG +, SD-). Furthermore, the sum of these three percentages exceeds 50%, namely, the most common way that the knowledge points being described in the analyzed textbooks shows strong semantic gravity (SG + or SG + +) and weak semantic density (SD- or SD–). It indicated that knowledge points in the four series textbooks are commonly elaborated with less complexity and avoid more abstraction.

The Features of Semantic Gravity of "Common Substances" in Chemistry Textbooks

The semantic gravity of the knowledge points in "common substances" in the four series of textbooks is separately provided in Fig. 4, which is expressed in terms of the percentage of each code.

According to Fig. 4, some common features can be observed among the four series of textbooks when dealing with the abstraction of knowledge points. For example, the SG + code accounts for the largest proportion of semantic gravity in each of the series, while the SG– code occupies the smallest proportion in the three series (SHEP, SDEP, and GDEP). It indicates that the four series of textbooks generally deal with most of the knowledge points with strong semantic gravity, such as extending with two levels of messages, and rarely explicate knowledge points at a minimal level of semantic gravity, except for PEP. Comparing the four series of textbooks in terms of the concept of semantic gravity, some uniqueness can be uncovered. First, in the PEP version, the SG– code accounts for the highest proportion, while SG + + accounts for the lowest proportion among the four series. What is special about PEP compared to the other three series of textbooks is that it

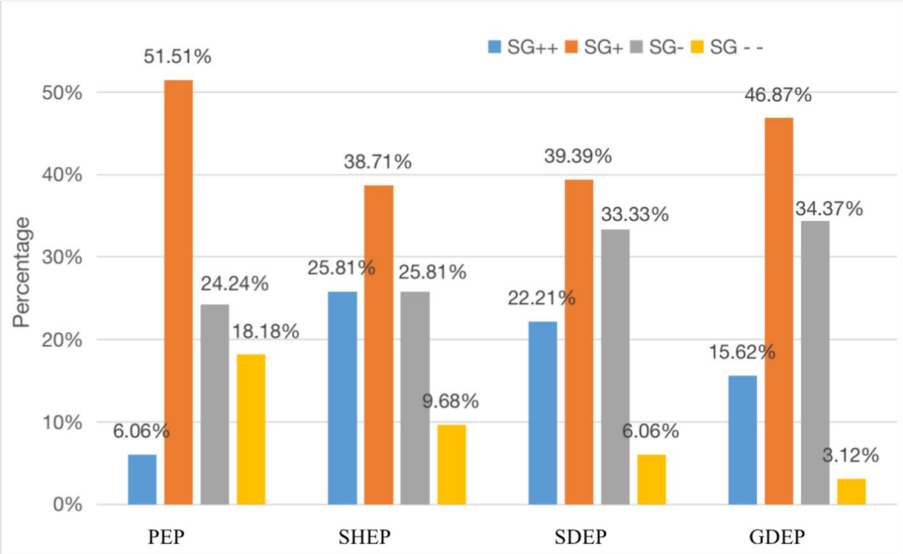

Fig. 4 The semantic gravity of the knowledge points under the topic of "common substances" in the four series of chemistry textbooks

tends to present knowledge points in terms of weaker semantic gravity (SG–) instead of stronger semantic gravity (SG++). In other words, unlike other series of textbooks, the PEP version appears to place a higher priority on a more abstract approach to presenting knowledge points rather than providing extremely concise and specific explanations. Second, it was found that SG++and SG- codes share an equal proportion in the SHEP version. This uniqueness indicates that the SHEP version equally emphasizes presenting knowledge points with both stronger (SG++) and weak semantic gravity (SG-).

The Features of Semantic Density of "Common Substances" in Chemistry Textbooks

The semantic density of the knowledge points under the topic of "common substances" in the four series of textbooks is separately demonstrated in Fig. 5. Given that not all knowledge points were covered by the four series of textbooks, comparing the count of each code makes no sense; thus, the data is represented as a percentage of each code relative to the total count of all codes in the chemistry textbooks under study.

From Fig. 5, some common features can be identified when dealing with the complexity of knowledge points among the four series of textbooks. For example, it can be observed that the percentages of four codes of semantic density in the four series of textbooks show the same trend: the stronger the semantic density, the smaller its percentage, namely, as the complexity of knowledge points increases, the percentage of its occurrences decreases. Under such a tendency, the SD– code has the largest percentage, while the SD++code has the smallest proportion in all of the four series textbooks. It indicates that knowledge points are rarely elaborated in an extremely detailed manner in all the four series of textbooks. Furthermore, it can be observed that more than 70% of the knowledge points were

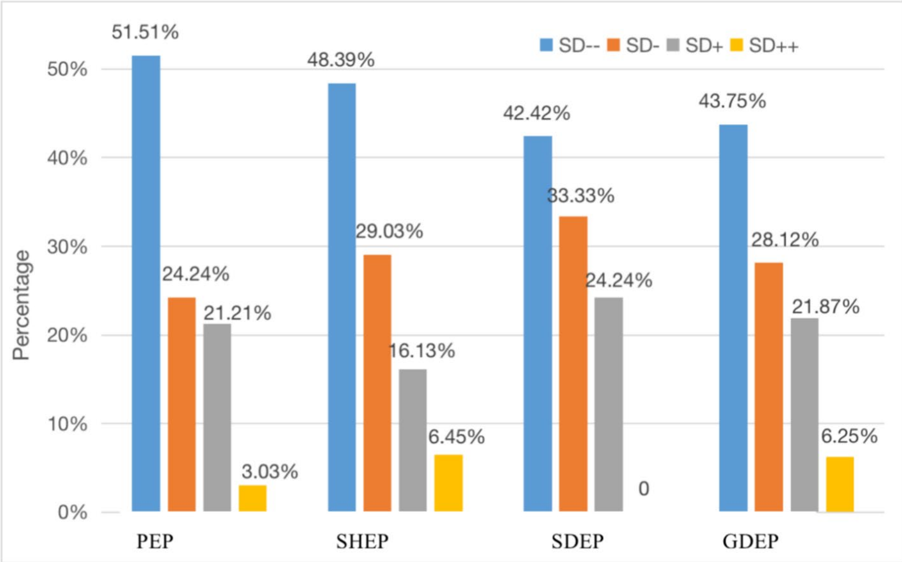

Fig. 5 The semantic density of the knowledge points under the topic of "common substances" in the four series of chemistry textbooks

classified as SD– and SD- codes in all the four series of textbooks, indicating that a significant proportion of the knowledge points are not presented in detail but just in a simple manner.

Comparing the four series of textbooks with regard to the semantic density dimension, some uniqueness can be found. First, SD- and SD + in PEP version share a comparable percentage when compared to other three series. Based on this finding, it appears that although the PEP version of the textbooks prioritizes weaker semantic density (SD–) to present knowledge points, it also recognizes the importance of the moderate strength of semantic density (SD + and SD-). Second, in the SDEP version, the percentages of the SD– and SD + + codes are both the lowest among the four series, with SD + + completely absent. In contrast, the proportion of the SD- and the SD + is the largest, the sum of their proportion is more than half, accounting for 57.57%. This suggests that the SDEP version of the chemistry textbook places a greater emphasis on the reduction of the complexity of the content, as evidenced by the less use of the more complex semantic codes (SD + +) and the more use of the less complex codes (SD- and SD +).

Discussion

It is common practice in many of the nations in the world to compile textbooks under a national curriculum especially in the stage of compulsory education in order to ensure the basic quality of education. It is expected that textbooks are aligned with the curriculum in terms of specific learning contents (Devetak & Vogrinc, 2013). As argued earlier, however, since textbooks are compiled by diverse author groups and published by various presses, the same topic of scientific knowledge could be represented with different degrees of abstraction and complexity in different series of textbooks, which will directly impact the implementation of the intended curriculum. Based on the principles of LCT (Semantics), we explored the representation of the abstraction and complexity of the 34 knowledge points under the topic "common substances" stipulated in the NCCS in China (MoE 2022) in the four series of chemistry textbooks with the aim of shedding light on this issue. As indicated in the overall semantic plane, the sum of three coding combinations ((SG+, SD–), (SG++, SD–), and (SG+, SD-)) accounts for more than half of the total (129), implying that using specific (SG+; SG++) and simple (SD-; SD–) way to explain knowledge points is a commonality to present knowledge points across the four series of chemistry textbooks under study. The further analysis of semantic gravity and semantic density of the knowledge points in each series of chemistry textbooks has displayed two common features. First, the SG+code accounts for the largest proportion in each of the series, implying that the four series of chemistry textbooks represent the knowledge points with strong semantic gravity. Second, the overwhelming majority of the knowledge points were classified as the SD– and SD- codes in all of the four series, indicating knowledge points did not have many meanings condensed, reflecting the less strength of semantic density. These findings have challenged a common observation that the language of textbooks often displays stronger semantic density (i.e. a lot of ideas are condensed within terms) and relatively weaker semantic gravity (i.e. the knowledge deals with more abstract principles) (Matruglio et al., 2013). Our findings can be used illustrate that the authors of the chemistry textbooks under study made an effort to make the information specific and simple to facilitate students' learning and comprehension. This is consistent with the aim of many school textbooks, which often strive to make the content accessible, readable and understandable to students with varied kinds of prior knowledge (Nwafor et al., 2022). Considering the nature of chemistry in the stage of compulsory education, which is purported to achieve scientific literacy for all students (MoE 2022), the degree of the abstraction and complexity of the knowledge points represented in the four series of chemistry textbooks under the topic "common substances" is appropriate.

Apart from common features among the four series of chemistry textbooks, uniqueness has been found in this study. Here, we would take the PEP series as an example. As the results showed, the PEP represents knowledge points as primarily having the weaker semantic density (SD–) and the moderate strength of semantic density (SD-, 24.24% and SD+, 24.21%) as well. This indicates that the PEP aims to strike a balance between simple and complex when presenting scientific knowledge in textbooks. In terms of semantic gravity, as the results showed, in contrast to the other three series of textbooks, which exhibit a significantly higher percentage of SG++codes than SG–, the PEP series displays a larger proportion of SG– than SG++. Compared with the other series, the PEP appears to prioritize a more abstract approach to presenting knowledge points rather than providing extremely specific explanations. Since textbooks were edited and compiled by various authors or author groups, who have freedom to develop their own approach to the delivery of the national curriculum, they represent a considerable diversity (Devetak & Vogrinc, 2013). These discrete features embodied in the various series of chemistry textbooks can be explained by the author effect (Abd-El-Khalick et al., 2017). An aspect of the author effect is that a certain author group would assume particular needs of the potential users of textbooks. For instance, as the national press, PEP is mainly responsible for publishing primary and secondary textbooks, and in fact, its series is widely used in many administrative regions in China. To care for various needs and teaching conditions across this country, the authors of the PEP series might tend to treat the knowledge points with either a strong semantic gravity (SG+) or the weaker semantic gravity (SG–). By presenting content with varying degrees of semantic gravity, the PEP series may be able to engage students with different learning preferences and provide a more comprehensive understanding of the subject matter.

The significance of this study for the research and practice of science education lies in several aspects. First, this study has advanced the research on intellectual demands of science knowledge. Concentrating on knowledge points stipulated in the national chemistry curriculum (MoE 2022), this study has displayed commonalities and differences of their representation among various series of chemistry textbooks in terms of abstraction and complexity. In this sense, it has extended the scope of the previous study conducted by Lee and Wan (2022), which focused on the intended science curricula. Second, we have developed a new scheme for quantifying the strengths of SD and SG in this study. As we know, semantics is one dimension of LCT and research has shown that the strength of semantic gravity and semantic density is not fixed or strictly defined, and the specific forms they take can vary depending on the objects and data (Maton, 2020). When applying the LCT (semantics) to textbook analysis, a translational process needs to be tailored to research contexts (Lee and Wan, 2022). In the context of this study, the extent of a certain knowledge point extended by the textbook serves as the basis for assessing semantic gravity and the degree of detail of a certain knowledge point embodied in the textbook serves as the basis for assessing semantic density. The criteria for differentiating the strengths of SG and SD (Table 3) can be used by other researchers to analyze chemistry or other subject-based science textbooks. Third, the findings of this study would provide professional supports for chemistry teachers' autonomy and responsibility in selecting chemistry teaching materials. In China, for instance, chemistry teachers used to adhere to a certain series of textbooks provided by school authorities and use it to define the scope and depth of their daily teaching. In recent years, however, chemistry teachers' autonomy is encouraged and they have freedom to compare and select the teaching content from various series of textbooks available on the market. The findings of this study concerning the abstraction and complexity of knowledge points will be beneficial for them to select appropriate chemistry content for their class. Last but not least, this study has broadened the vision of good quality of science textbooks from the perspective of social linguistics. According to Valverde et al. (2002), "textbooks help define school subjects as students experience them. They represent school disciplines to students" (p. 1). Thus, the most important criterion for a good science textbook is that the degrees of abstraction and complexity of scientific knowledge suit the development of students, their understandings about and experiences with science concepts. As revealed in this study, semantic codes are mostly found in the prosaic quadrant while some are in other three quadrants (see Table 4), which is thought to be appropriate given the nature of the subject of chemistry at the stage of compulsory education. The findings of this study would be helpful to reaffirm a novel vision that the appropriate strength of abstraction and complexity of scientific knowledge represented in science textbooks should not be confined by the dichotomy between theoretical (quadrant 1) and practical (quadrant 3) but explore the possibility of "rarefied" (quadrant 2) and "worldly" (quadrant 4) suggested in the semantic plane (see Fig. 1).

It is noteworthy that this study focused on only one topic of chemistry content stipulated in the NCCS (MoE 2022) in China. It should be very prudent to generalize the findings to the other topics of chemistry content in the stage of compulsory education. We are looking forward to seeing future studies that focus on other themes or topics of chemistry in the stage of compulsory education. Moreover, some studies could be conducted on textbooks of other subjects (such as biology, physics) and beyond the stage of compulsory education. Finally, it should be acknowledged that this study is exploratory in its nature in that descriptive statistics was used to analyze the data collected from the four widely adopted series of chemistry textbooks. In the future, more series of chemistry textbooks or more themes or topics could be involved and advanced statistical techniques could be used to yield more robust results concerning the issues under investigation.

Data Availability The data and materials used and analyzed for this article are textbooks that are available in the market.

Declarations

Ethics This study involves no human participants. It meets all the ethics requirements of (Details withheld to preserve blind review) at the time the data were collected.

Competing Interests The authors declare that they have no competing interests.

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