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Constructing written scientific explanations: a conceptual analysis supporting diverse and exceptional middle- and high-school students in developing science disciplinary literacy

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Constructing a written scientific explanation is a science practice that is fundamental in supporting students developing understanding of the natural world in which we live. Engaging in the practice of constructing valid scientific explanations supports students in developing science disciplinary literacy. Yet, writing a scientific explanation can be challenging for diverse and exceptional learners because it requires coordinating multiple, complex skills. This conceptual analysis explores the purpose of constructing written scientific explanations by focusing on the constituent elements and structures of a constructed scientific explanation. These findings are then integrated into a framework to assist Individual Education Program (IEP) teams in planning and implementing successful supports and instruction for diverse and exceptional learners in middle- and high-school, general education, science classrooms.

KEYWORDS

science education, diverse and exceptional learners, writing, scientific explanations, graphic organizer

1 Introduction

Constructing a written scientific explanation is a science practice identified by the National Research Council, (2012) and Next Generation Science Standards (NGSS Lead States, 2013) as fundamental in supporting students developing understanding of the natural world in which we live. The process of constructing a valid scientific explanation involves multiple facets culminating in a paragraph that provides a clear, valid scientific explanation for the phenomena being explored. This, in turn, supports students in developing more complex knowledge related to the discipline of science, but also supports them in using written language across academic domains (Shanahan and Shanahan, 2012; Torgesen et al., 2017; Grysko and Zygouris-Coe, 2020). Constructing scientific explanations may be challenging for diverse and exceptional learners because it requires coordinating multiple, complex skills (e.g., handwriting, generating ideas, forming sentences, making arguments; Graham et al., 2020). This conceptual analysis explores the purpose of constructing written scientific explanations by focusing on the constituent elements and structures of a constructed scientific explanation as situated within the specific needs of diverse and exceptional learners in middle- and high-school general education, science classroom settings. Attention is given to identifying the specific strengths and areas of need of diverse and exceptional learners, how to set achievable goals for them related to writing constructed scientific explanations, and instruction and supports needed to ensure their success.

In 2012, the National Research Council published *A Framework for K-12 Science Education* as a guide to support educators in developing students' fundamental knowledge of science phenomena (National Research Council, 2012). Historically, science instruction has focused primarily on students' accumulation of science facts (Sandoval, 2003; Tang, 2015). The framework, which led to the development of the Next Generation Science Standards (NGSS Lead States, 2013), identifies three dimensions of learning that progress across grade levels: crosscutting concepts (e.g., ideas that link across science domains such as patterns or cause and effect), disciplinary core ideas (e.g., for life, earth/space, and physical sciences; engineering, technology, and application of science), and science and engineering practices. The three dimensions of learning support students in developing sufficient knowledge of science to understand basic phenomena and be conscientious consumers of scientific information. This level of scientific understanding involves "engaging in the *practices* [italics our own] of inquiry and the discourses by which such ideas are developed and refined (National Research Council, 2012, p. 218)."

NGSS science and engineering practices (see Table 1) help students to understand how scientific knowledge is developed over time and instill an appreciation of the broad ways in which to investigate, model, and explain phenomena in the world (National Research Council, 2012). This in turn supports students in understanding how science can meet challenges we face in society. Furthermore, doing the active work of scientists is motivating and engaging and holds the potential to lead to deeper conceptual understandings (Elander et al., 2006; National Research Council, 2012). One of the eight science and engineering practices identified in the NGSS is constructing explanations (National Research Council, 2012; NGSS Lead States, 2013). As noted in the framework, "Because science seeks to enhance human understanding of the world, scientific theories are developed to provide explanations aimed at illuminating the nature of particular phenomena, predicting future events, or making inferences about past events (National Research Council, 2012, p. 67)." Yet, constructing written scientific explanations requires students to engage in other practices as well. They must be able to ask questions and define problems (Practice 1), analyze and interpret data (Practice 4), and engage in arguments from evidence (Practice 8).

Constructing scientific explanations, Practice 6 of the NGSS science and engineering practices (NGSS Lead States, 2013), is defined specifically as "a claim that relates how a variable or variables relate to another variable or a set of variables" (NGSS Lead States, 2013, Appendix F, p. 11). Claims are generally made in response to a question that is related to an observed phenomenon. Scientists investigate phenomena to generate data which is then used as evidence to support the stated claim. The evidence generated is then linked to proven scientific theories (National Research Council, 2012).

This conceptual analysis begins with an examination of the scientific practice of constructing written scientific explanations. In this section, the outcome of constructing explanations is explored, as situated within the larger domain of developing disciplinary literacy. Then, the constituent elements and structures that form a constructed scientific explanation are described. In the next section, an overview of the writing challenges faced by diverse and exceptional students is presented, specifically as applied to the constituent elements and structures of constructing a written scientific explanation. In the final section, Cognitive Load Theory (Paas et al., 2003; Sweller et al., 2011; Sweller, 2020) is presented as a foundational framework for supporting diverse and exceptional students in constructing written scientific explanations, specifically to assist Individual Education Program (IEP) teams in planning and implementing successful supports and instruction for diverse and exceptional learners in middle- and high-school, general education, science classrooms.

2 Constructing written scientific explanations

2.1 Why should students construct written scientific explanations?

Developing academic literacy is a primary objective of K-12 schooling. Academic literacy is defined as the proficiency required to construct meaning in content-specific subjects most often associated with schooling (e.g., science, social studies, English language arts; Torgesen et al., 2017). Academic literacy consists of proficiency in the use of the language and discourse inherent within a domain (i.e., reading, writing, speaking, listening) and is developed as students read, write, and speak more broadly across multiple disciplines (Shanahan and Shanahan, 2012). Educators support students in developing academic literacy by explicitly teaching structures of academia, such as: (1) how texts are organized, (2) understanding the use of resources to support textual information, and (3) using resources to construct texts (Meneses et al., 2023). Specific genres, such as knowing the difference between fiction and non-fiction and understanding the function of non-fiction texts, are related to fully developing academic literacy. As Patterson and Weideman (2013) argued, language is specific to contexts and situations in which it happens, and such contexts influence the meaning to be learned. Gee (2014) clarified literacy, as related to language development within discourse, as a social practice which is linked to disciplinary epistemology as well as one's identity. Thus, academic literacy is not a discrete set of skills students learn (e.g., how to identify cause and effect, how to compare and contrast objects or ideas), but should be viewed through the socialization and participation of students engaged in meaningful and authentic practices within a disciplinary domain (Li, 2022).

Disciplinary literacy, on the other hand, is defined as discipline specific. Disciplinary literacy relates to the knowledge, discourse, and tools used by experts within the field to engage in the work of the field (Shanahan and Shanahan, 2012). In science, this aligns with the purpose and goals of the NGSS (NGSS Lead States, 2013) that students engage in the inquiry practices of scientists by carrying out scientific investigations, identifying sufficient evidence, and applying crosscutting themes to deepen their understanding of natural phenomena. As Grysko and Zygouris-Coe (2020) noted, science disciplinary literacy involves engaging in reading and writing related

TABLE 1 NGSS science and engineering practices.

Practice	Description from the NRC Framework (2012)
1. Asking Questions and Defining Problems	"Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations (National Research Council, 2012, p. 56)."
2. Developing and Using Models	"Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system (National Research Council, 2012, p. 58)."
3. Planning and Carrying Out Investigations	"Students should have opportunities to plan and carry out several different kinds of investigations during their K-12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from students' own questions (National Research Council, 2012, p. 61)."
4. Analyzing and Interpreting Data	"Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence (National Research Council, 2012, p. 61–62.)"
5. Using Mathematics and Computational Thinking	"Although there are differences in how mathematics and computational thinking are applied in science and in engineering, mathematics often brings these two fields together by enabling engineers to apply the mathematical form of scientific theories and by enabling scientists to use powerful information technologies designed by engineers (National Research Council, 2012, p. 65)."
6. Constructing Explanations	"Asking students to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed, engages them in an essential part of the process by which conceptual change can occur (National Research Council, 2012, p. 68)."
7. Engaging in Argument from Evidence	"The study of science and engineering should produce a sense of the process of argument necessary for advancing and defending a new idea or an explanation of a phenomenon and the norms for conducting such arguments (National Research Council, 2012, p. 73)."
8. Obtaining, Evaluating, and Communicating Information	"Any education in science and engineering needs to develop students' ability to read and produce domain-specific text. As such, every science or engineering lesson is in part a language lesson, particularly reading and producing the genres of texts that are intrinsic to science and engineering (National Research Council, 2012, p. 76)."

to "scientific inquiries, constructing evidence-based explanations, and communicating their ideas and observations to others" (p. 487). More specifically, the literacy practices utilized by scientists involve observing a phenomenon, formulating questions, seeking answers through explorations and experiments, describing observations and data, and making claims regarding evidence that is linked to proven scientific theories (Sandoval, 2003; Fang, 2013; Tang, 2016; Meneses et al., 2023). These discursive practices involve reading, writing, speaking, and listening – the language of science literacy.

As students proceed through school, their disciplinary literacy in science develops, from naïve perspectives to deeper scientific understandings (Federer et al., 2015). Developmental psychologists have determined that children's developing ideas progress over time (Duncan and Hmelo-Silver, 2009). In 2007, the National Research Council applied these developmental theories as learning progressions in science, which have been expanded over time to reflect how students' understanding evolves into more sophisticated ways of reasoning to explain phenomena as they develop disciplinary literacy in science (Duncan and Rivet, 2013). Learning progressions are empirically grounded, testable hypotheses of how students' thinking evolves across grade levels (Corcoran et al., 2009). Learning progressions have been defined as "sequences of successively more complex ways of thinking about an idea" (Smith et al., 2006, p. 5). Similarly, students' ability to construct scientific explanations is expected to evolve over time. According to the NGSS (NGSS Lead States, 2013), students in kindergarten through 2nd grade are expected to make observations, use tools, and generate a solution to a problem. By 12th grade, students should be able to construct an explanation using their knowledge of accepted scientific principles and link that explanation to evidence, use evidence to support or refute their explanation, provide causal explanations, and evaluate their own and other's explanations, using scientific knowledge (National Research Council, 2012).

Galloway and Uccelli (2015) defined disciplinary literacy as a 'macro-genre (p. 798)' that consists of building blocks, or 'academic micro-genres,' that support students in becoming literate in science as a discipline. Micro-genres include discourse-level organizational structures that are used in science texts (e.g., classifications, comparing, causal effects), and, like learning progressions, evolve in complexity over time. Developing fluency in an academic language is more than just the accumulation of vocabulary but involves a broader accumulation of language skills (Galloway and Uccelli, 2015). Constructing a written scientific explanation, therefore, is a micro-genre of science, and doing so involves complex skills. Elander et al. (2006) argued that academic writing involves subject knowledge combined with personal qualities (e.g., motivation, attitude) and social practices to construct new knowledge. As a student progresses through school, they learn to write first, then write to learn in content classrooms such as science (Meneses et al., 2023). As Galloway and Uccelli (2015) argued, "Writing to communicate learning is a linguistic task which depends on having a host of language resources" (p. 798). Thus, students should construct written scientific explanations because doing so has them actively engaged in the inquiry practices of science, in building new knowledge, and integrating that new learning into more complex understanding of phenomena occurring in our natural world.

2.2 What constitutes a constructed scientific explanation?

A major goal of learning science in school is for students to become scientifically literate, to be able to effectively read claims, such as in the news or in magazines, and be able to determine if they are credible or valid (McNeill and Krajcik, 2008). To arrive at that point, students need "an epistemic understanding of the criteria for explanations" (Sandoval, 2003, p. 7). The basic purpose of a constructed scientific explanation is to answer "why" or "how" questions rather than just "what" questions (Federer et al., 2015). Writing a scientific explanation is a more elaborative form of writing that requires students to transform information rather than just record it (e.g., taking notes, writing observations; Klein, 2004). A constructed scientific explanation involves three constituent elements – claim, evidence, scientific principle – and dialectical structures required to glue all the parts together (Figure 1).

2.2.1 Claim

The claim is a statement or conclusion that answers a question that has been posed related to the phenomenon being examined (see Figure 1; McNeill et al., 2006). For example, students in a 7th grade classroom observe their teacher pour vinegar into a glass beaker that has baking soda in the bottom. Prior to pouring in the vinegar, the class has conducted an observation of the two substances. Baking soda is a white powder that is odorless, and vinegar is a clear liquid that has an odor. They observe bubbles forming and hear a fizzing sound when their teacher pours the vinegar into the baking soda. Once the bubbling and fizzing stops, there is no longer a white powder or a clear liquid. Instead, gas was released. The teacher asks a question: Did a new substance form when baking soda and vinegar are mixed? The response students write is a claim.

A claim addresses the target phenomenon (Lee and de la Paz, 2021) which describes what students observed. The claim consists of entities, which play a role in the mechanism of the phenomenon, and activities which include how the entities acted or what they were doing (Lee and de la Paz, 2021). In the classroom example above, a reasonable claim which answers the question posed would be, "When Mr. Hines poured vinegar into baking soda, gas was released, so a new substance was formed." In this statement, the target phenomenon, which is a cause and an effect, was "a new substance was formed." The entities, which are nouns, were "baking soda," "vinegar," and "gas." The activities, which are verbs, were "poured," "released," and "formed."

2.2.2 Evidence

Evidence supports the claim statement and comes from multiple sources, such as text, data that is provided (e.g., charts, graphs), data that is observed and collected, or models. Evidence must be coordinated to either support the claim or refute it (see Figure 1; Sandoval and Millwood, 2005). Appropriate evidence must be evaluated to ensure it supports the claim and can be confirmed by others (AAAS, 2017) and sufficient evidence must be in place to convince others that the claim is relevant (McNeill and Krajcik, 2008). To ensure evidence is appropriate and sufficient, critical thinking and reasoning are needed (Elander et al., 2006), specifically the ability to evaluate one's evidence to support the claim (McNeill et al., 2006). Questions that should be asked include: (1) what evidence exists to support the claim, (2) what are the evidence sources (data, observations, modeling), (3) is the evidence sufficient and consistent, and (4) is there evidence that does not support the claim and why not? Reasoning provides the foundation for what evidence is selected, and why it adequately supports the claim (McNeill et al., 2006).

In the example above, the evidence to support the claim includes the following:

1. Baking soda is a white, odorless, solid powder. Vinegar is a clear, smelly liquid. A colorless, odorless gas was produced when they were mixed.
2. A positive limewater test on the new substance showed carbon dioxide was present.
3. The ball and stick molecular models of baking soda and vinegar were rearranged to produce molecular models of carbon dioxide, water, and sodium acetate.
4. The molecular models showed that atoms (NA, H, C, O) that made up the molecules in baking soda and vinegar were disconnected and then reconnected in new ways to form molecules for the new substances (carbon dioxide, water, and sodium acetate).

Writing evidence statements requires the use of scientific vocabulary (e.g., molecules, atoms) and disciplinary knowledge related to the phenomena of study. In this classroom example, students must have some background experience with molecular models to understand how atoms make up molecules and can be broken down and reattached to make different molecules.

2.2.3 Scientific principle

Scientific principles are accepted ideas, laws, or rules that are generalizable, well accepted within the scientific community, and theoretically account for why or how a phenomenon occurs (see Figure 1; McNeill et al., 2006; National Research Council, 2012; Tang, 2015). For students, scientific principles help them make sense of their world (Sandoval and Millwood, 2005). As students apply a scientific principle to support evidence of their claim, a deeper connection to content knowledge is forged (McNeill and Krajcik, 2008). Linking evidence to scientific principles requires foundational knowledge of generalizable, natural laws as well as the ability to discern which scientific principle to apply (AAAS, 2017).

An example of a scientific principle is: "Every substance has a unique set of properties, such as odor, color, density, melting point, conductivity and solubility, and these can be observed or measured" (AAAS, 2017). Scientific principles such as this have been confirmed by scientists based on a wide range of data collected and observed and can be readily applied by students when conducting observations or collecting their own data. In the classroom example above, students have been explicitly taught by Mr. Hines the scientific principle stated above and it is posted in the classroom. This principle then supports the evidence that they have collected and used to support their claim. Another scientific principle that Mr. Hines' students could use is that new substances are formed through chemical reactions where the original substances' properties are changed into the properties of a new substance.

Once all the constituent elements (claim, evidence, scientific principle) are in place, the constructed scientific explanation is written. For the classroom example presented here, a valid explanation would be as follows:

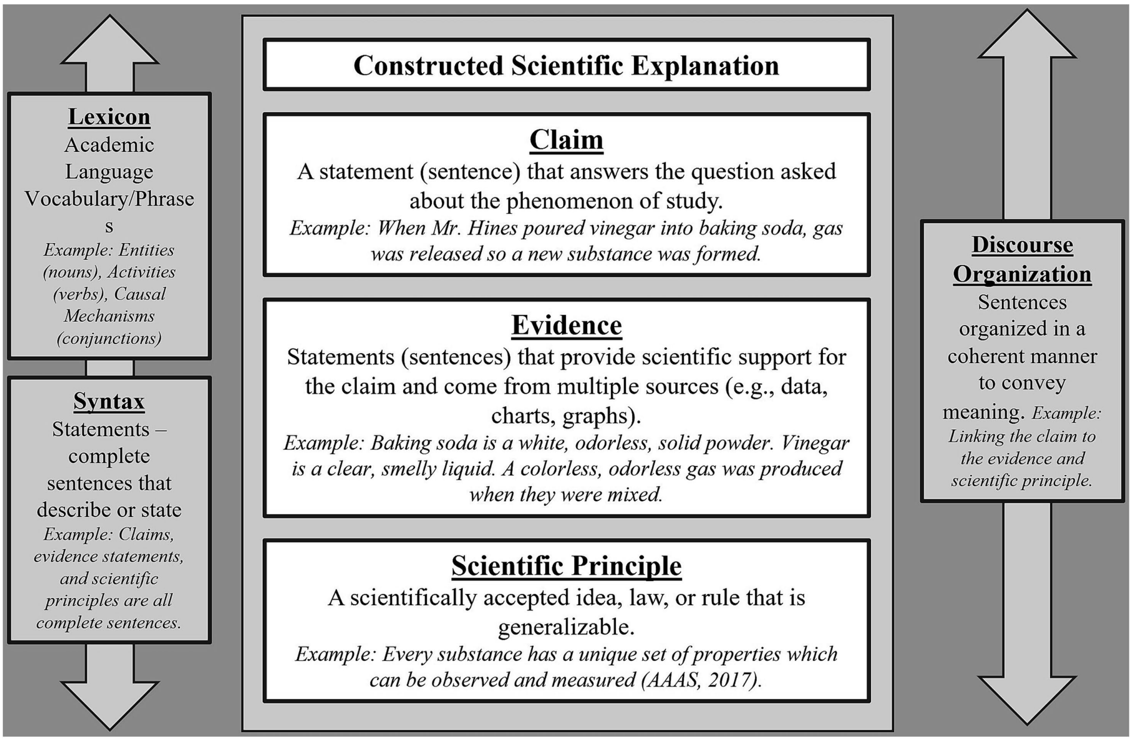

FIGURE 1
Constituent elements and dialectical structures of a constructed scientific explanation.

> Carbon dioxide was produced from a chemical reaction when baking soda and vinegar were mixed. The properties of baking soda and vinegar changed when the chemical reaction occurred, and the atoms were rearranged into new molecules. We know that carbon dioxide was produced because the limewater turned cloudy. Finally, we know that a new substance is produced when a chemical reaction occurs (Science Idea).

2.2.4 Dialectical structures

As noted by the National Research Council, (2012), scientific explanations "link scientific theory with specific observations…they explain observed relationships between variables and describe the mechanisms that support cause and effect inferences about them" (p. 67). When constructed, a scientific explanation is rhetorical, serving the purpose of organizing claims, evidence, and scientific principle into a persuasive account (Sandoval and Millwood, 2005; Galloway and Uccelli, 2015). Argumentation, with the intention of persuasion through appropriate, sufficient evidence, backed by scientific principle, is a science practice because there can be competing explanations for phenomena (National Research Council, 2012). Thus, constructing a written scientific explanation requires argumentation to justify the validity of the explanation (Yang and Wang, 2014). For students, the ability to engage in argument can be motivating, transforming students from passive recipients of facts to active constructors of knowledge (Elander et al., 2006). To unpack the literacy and language skills needed to piece together the claim, evidence, and scientific principles, students need dialectical structures (see Figure 1; Meneses et al., 2023). The dialectical structures that support the constituent elements of a constructed scientific explanation include lexicon, syntax, and discourse organization.

2.2.4.1 Lexicon

Lexicon consists of the academic language of science, which becomes more complex and precise over time as students move through school (see Figure 1; Galloway and Uccelli, 2015). In the example provided above, students used specific science lexicon - vocabulary and phrases - related to the phenomenon of study (e.g., molecules, atoms, carbon dioxide, chemical reaction). Lexicon also relates to a basic understanding of how words are used, specifically, the complete set of meaningful linguistic units in the development of language (Gee, 2018). To write a claim statement, students must understand that entities are nouns which provide the name of things (e.g., Mr. Hines, baking soda, vinegar) and activities are action verbs which describe an action (e.g., pour, release, form). Students must also understand how conjunctions are used to connect ideas, specifically in causal relationships (e.g., first, then, next, last; Lee and de la Paz, 2021).

2.2.4.2 Syntax

Syntax refers to how words are arranged into sentences to convey meaning. Before students can write a claim, they must understand what constitutes a complete sentence, which is a statement that expresses a complete thought (see Figure 1; Gee, 2018). Just as lexicon grows in complexity and precision over time, syntax must as well (Galloway and Uccelli, 2015). Putting lexical structures together into sentences in the context of learning science requires mechanistic reasoning, thinking about chains of events, causal connections, making analogies, and coherence (Sandoval, 2003; Lee and de la Paz, 2021; Meneses et al., 2023). Students must be able to use syntax to describe, such as when they select and identify evidence (Elander et al., 2006; Seah, 2016). They must also use syntax to explain, which differs from description by adding causal mechanisms and coherence (Seah, 2016; Lee and de la Paz, 2021).

In the constructed scientific explanation above, each sentence represents a constituent element. For example, the first sentence is the claim statement – "Carbon dioxide was produced from a chemical reaction when baking soda and vinegar were mixed" – which includes the target phenomenon, entities, and activities. The last sentence is the scientific principle – "We know that a new substance is produced when a chemical reaction occurs (Science Idea)" – which includes a parenthetical note to confirm origin of the principle. And the middle sentences provide the evidence to support the claim. Each sentence requires knowledge of both lexical structures and syntax (e.g., use of the words "when" and "finally").

2.2.4.3 Discourse organization

A completed scientific explanation is a mechanistic accounting that seeks to persuade others by justifying a claim based on supporting evidence and scientific principles (see Figure 1; Tang, 2016). Thus, it involves more than just one sentence. A paragraph is generally considered to be a collection of connected sentences that express a distinct theme or topic. Students must understand how to link sentences together into paragraph form in an organized manner to persuade the reader that their claim is valid, based on accurate and sufficient evidence, and linked to a larger, accepted scientific principle (McNeill and Krajcik, 2008; AAAS, 2017). In the example provided above, the scientific explanation is constructed in a mechanistic manner, beginning with the claim, supported by several sentences describing the evidence, and ending with a link to a scientific principle that thus confirms the evidence and supports the claim.

3 Writing challenges for diverse and exceptional learners

Writing is inextricably connected to literacy development, and specifically connected to content learning (Graham et al., 2020). Writing, for any purpose or genre, requires multiple, complex skills (e.g., handwriting, spelling, generating ideas, organizing, ideas, drafting, revising, evaluating; Graham et al., 2016). For generally achieving students, the ability to write progresses as they move through school, from basic principles (e.g., how to form letters) to more complex tasks (e.g., arguing a position). Yet, for diverse and exceptional students, a gap forms in early elementary years between their writing proficiency and that of their peers, and widens as the grades progress (Vue et al., 2016). Data from the 2011 National Assessment of Educational Progress (U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics, National Assessment of Educational Progress (NAEP), 2011) demonstrated that 60% of students identified with a disability failed to meet basic writing proficiency standards. In a review of the literature on writing challenges, four specific writing skills emerged which proved particularly daunting for diverse and exceptional learners: planning and organizing ideas for writing, text production, revising and evaluating writing, and motivation and self-confidence (see Table 2).

Planning and organizing for writing is a pre-writing skill. Yet, research indicates that many diverse and exceptional students fail to demonstrate a plan prior to writing (Vue et al., 2016). In a meta-analysis of writing interventions, Gillespie and Graham (2014) found that students with exceptionalities spend less time than their general education peers in generating ideas for their writing. Instead, they often write to simply generate content. Their product tends to be one fact stated in a sentence followed by another fact stated in a sentence, and so on. The result lacks coherence, clarity, or purpose. Even if students do plan their writing, they find it challenging to coordinate those ideas into a cohesive product (Graham et al., 2013). Finally, executing a plan requires understanding of the purpose for writing as well as a clear understanding of the structures required for the genre (Graham et al., 2016). For example, writing a summary differs from writing a position essay, which in turns differs from writing a constructed scientific explanation. Therefore, planning and organizing ideas for writing is a critical thinking skill that must be explicitly taught to diverse and exceptional learners.

Text production is the physical process of writing and involves handwriting, mechanics (e.g., spelling, punctuation, grammar), and sentence fluency (Graham et al., 2016). Text production skills are generally explicitly taught in school, starting with basic handwriting in early elementary, and progressing across grade levels as more complex spelling patterns, punctuation, and grammar are taught. By the time general education students reach middle- and high-school, text production skills can become automatic. Yet that is not the case with diverse and exceptional learners. Even if diverse and exceptional learners have a writing plan in place, they can struggle with text production. Generating text may require more working memory (e.g., how to spell, use of correct punctuation, limited vocabulary), which then bogs down the writing process, minimizing what is produced (Gillespie and Graham, 2014; Graham et al., 2016). Therefore, diverse and exceptional students continue to need instruction in text production skills as well as practice in developing fluency in writing.

Revising and evaluating writing comes after text has been produced. Consistently, the research indicates that diverse and

TABLE 2 Writing challenges for diverse and exceptional learners.

Challenge	Description of skills needed
Planning and organizing	Generating ideas for writing Understanding the purpose for writing (essay, story, description) Setting goals Creating and executing a plan (tasks for completing writing)
Text production	Handwriting Mechanics (spelling, punctuation, grammar) Fluency (in handwriting, in flow of ideas, in persistence) Vocabulary (disciplinary specific)
Revising and evaluating	Mechanics (spelling, punctuation, grammar) Content (does it achieve the purpose for writing) Organization (paragraphs, ensuring argument)
Motivation and self-confidence	Setting goals (to ensure success) Understanding the purpose (makes writing meaningful) Building success to build confidence and self-esteem

exceptional students struggle with revising their work, spending less time than their general education peers in making revisions based on evaluations of what they have written (Gillespie and Graham, 2014). When they do revise their work, the focus is predominantly superficial with more attention given to mechanics (e.g., spelling, punctuation, grammar) and less given to evaluating the content of what was written or how it was organized (Vue et al., 2016). During elementary school, students are generally taught how to revise and edit their work with a focus more on the mechanics of writing. This then transitions in middle- and high-school so that there remains attention on mechanics, but the primary focus is on evaluating content. For diverse and exceptional learners, instruction must continue to focus on mechanics of writing, but must also support them in thinking about the content and how it is organized for the purpose of writing.

Motivation and self-confidence in writing provide the foundation for writing in the first place. "Motivational dispositions affect what writers do as writers with an 'I can do' attitude are more likely to plan, set challenging goals and persist as writers (Graham et al., 2016, p. 201)." The motivation to write comes first from an understanding of what purpose the writing serves, and why it is worthwhile to write, which then interacts with the writer's confidence in their ability to do so (Camacho et al., 2021). Motivated writers plan more effectively, are fluent in their text production, and evaluate their writing on a deeper, contextual level (Graham et al., 2013). For students who struggle to write, motivation is weakened. If a task is challenging, it is more likely that a student will avoid it completely (Gillespie and Graham, 2014). And, when diverse and exceptional learners avoid writing, they fail to build self-confidence (Graham et al., 2016; Vue et al., 2016). While motivation and self-confidence cannot be taught, they can be fostered over time as a student experiences success. Furthermore, when successful in writing, learning of the content follows (Graham et al., 2020).

4 A framework for constructing written scientific explanations

We utilize Cognitive Load Theory (CLT; Sweller et al., 2011; Paas and van Merriënboer, 2020) as a foundation for our framework for supporting diverse and exceptional learners in constructing written scientific explanations. CLT was developed as a theory of instructional design, specifically drawing from what is known about human cognition and then applying that knowledge to designing instruction that is beneficial to the learner (Sweller et al., 2011). Humans' "cognitive architecture (Sweller, 2020, p. 1)" – how cognitive structures and processes are organized – includes a working memory that is limited in both capacity and duration, particularly when introduced to novel ideas. Yet, that same working memory has unlimited capacity and duration when working with familiar information or knowledge that has been successfully stored in long-term memory (Sweller et al., 2011). Thus, instruction should be designed in a way to carry the load of working memory, transporting new knowledge into long-term memory to free up working memory again to engage in new learning. The focus of instruction should be on the learner (e.g., supports the learner needs), the learning task (e.g., how the task is taught), and the learning environment (e.g., broader contexts of learning; Paas and van Merriënboer, 2020).

Figure 2 displays the Framework for Constructing Written Scientific Explanations for diverse and exceptional learners in middle- and high-school, general education, science classrooms. For diverse and exceptional learners, working memory can be overloaded when planning and organizing ideas for writing, engaging in text production, and in revising and evaluating writing. Therefore, a framework is needed to carry that load so that deeper context knowledge can develop. Using CLT, the framework focuses first on the learner, specifically examining the learners' present level of academic achievement and functional performance (PLAAFP). Next, the framework focuses on the learning task, specifically examining how measurable goals for the learners' IEP are designed and what instruction and support the learner needs to engage in the task of constructing a written scientific explanation. Finally, the framework focuses on the learning environment, specifically examining how special educators should work in conjunction with general education science teachers to provide the context in which the learner is immersed in the practice of science inquiry and is supported in transitioning learning into long-term memory.

4.1 The learner

4.1.1 Present levels of academic achievement and functional performance

The framework begins by focusing on the specific learner's present levels of academic achievement and functional performance (PLAAFP). A PLAAFP statement, a fundamental component of the IEP for a diverse and exceptional learner, is a summary of the learner's strengths and needs across multiple academic or functional areas. From there, the IEP team can write measurable goals, and design instruction that will explicitly address identified needs. To construct a written scientific explanation, the framework guides educators in focusing on what skills are in place and what skills are needed for a diverse and exceptional learner to successfully construct a written scientific explanation. We developed Figure 3 as a planning guide for the IEP team to use in determining what skills a diverse and exceptional learner will need to successfully construct a written scientific explanation. This step-by-step guide begins with considering lexicon (e.g., can the learner identify nouns, verbs, and conjunctions), and then moves to considering if the learner understands syntax (e.g., what are clauses, sentences, compound sentences). Each of the four writing skills are addressed in questions related to discourse organization (e.g., can the learner plan and organize, produce text, revise and edit, is the learner motivated and self-confident). Finally, the PLAAFP statement must address: (1) the dialectical structures (e.g., lexicon, syntax, discourse organization) that link the constituent elements of a constructed scientific explanation, and (2) the four writing skills needed (e.g., planning and organizing ideas for writing, text production, revising and evaluating writing, and motivation and self-confidence).

The dialectical structures that link constituent elements of a constructed scientific explanation include lexicon, syntax, and discourse organization (see Figure 2). When situated within a constructed scientific explanation, these structures are context specific (e.g., life science, earth science, physical science). However, these structures are foundational to overall academic literacy (e.g., history,

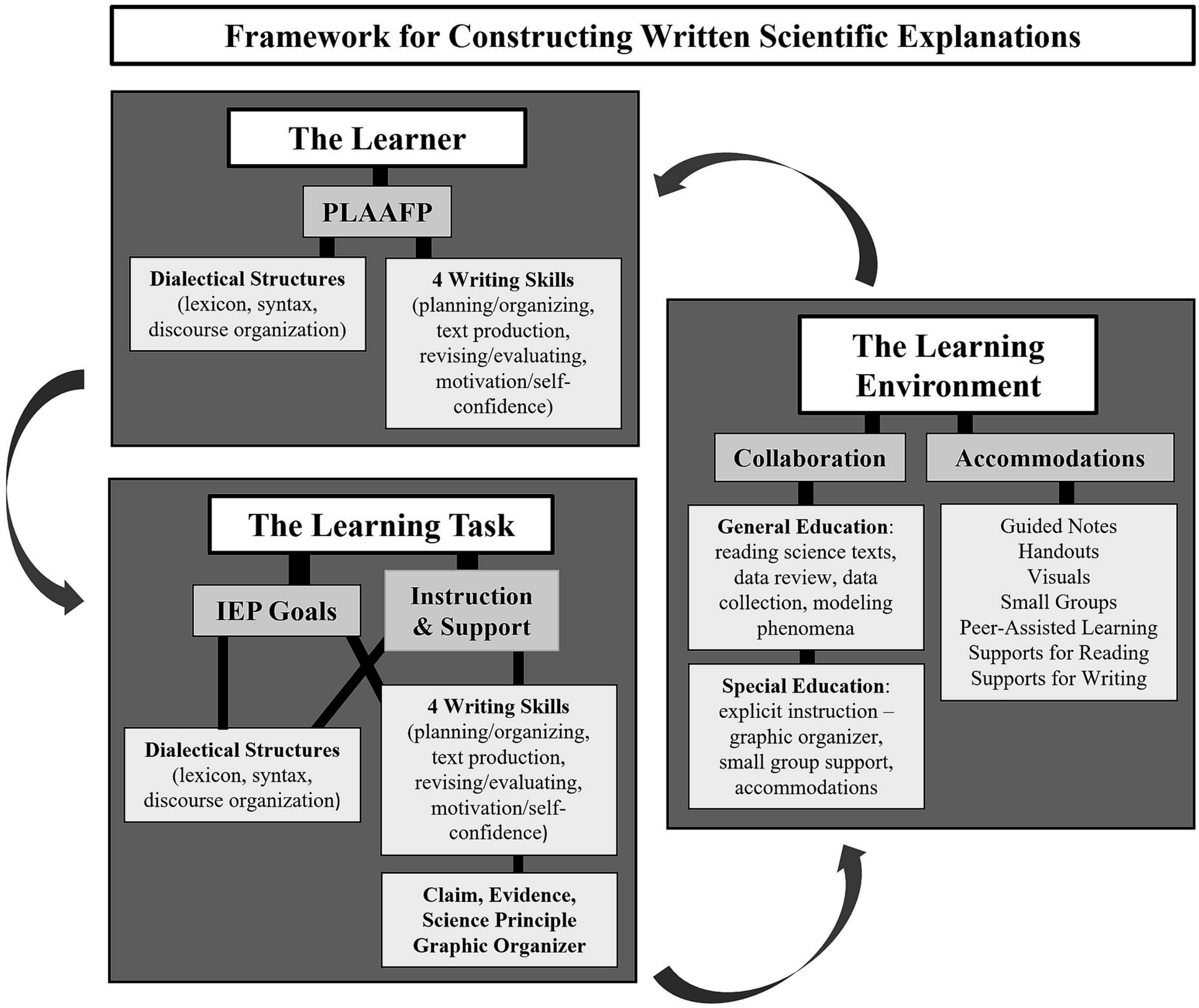

FIGURE 2
Framework for constructing written scientiific explanations.

social studies, English language arts), so addressing them in the IEP serves a more holistic goal of supporting academic writing in general. When evaluating a learners' lexical knowledge, the IEP team should assess the learner's grammatical skills related to parts of speech (e.g., nouns, verbs, conjunctions), as these are vital to understanding how the claim statement is constructed (e.g., entities, activities) and how the evidence will be linked in a causal manner (e.g., first, next, last). While there are diagnostic assessments related to grammar available, a curriculum-based measurement (CBM) could be readily developed by the IEP team. An evaluation of the learner's skill with syntax should consider how effective the learner is in constructing complete sentences and their ability to understand what constitutes a complete sentence. Finally, the IEP team should assess the learner's discourse organization, specifically their ability to construct a complete paragraph that is coherent and grammatically accurate. Both syntax and discourse organization could be assessed using curriculum-based measurements or using informal writing assessments to measure paragraph composition (Suastra and Menggo, 2020).

The four writing skills required of constructing a written scientific explanation include planning and organizing ideas for writing, text production, revising and evaluating writing, and motivation and self-confidence. While these are context specific for constructing a written scientific explanation, they are also universal writing skills related to academic literacy, and thus useful across content areas in school. Englert et al. (1991) developed a model for evaluating five writing steps - plan, organize, write, edit, and revise (POWER) – which provides a quick assessment of how well a learner is doing in planning and organizing for writing, engaging in text production, and revising and evaluating their work. Text production skills should be considered as well: can the learner physically write or do they need word processing software, how well is their spelling or do they need more explicit instruction in spelling patterns, how is their punctuation and grammar, and can they fluently draft sentences together to form a paragraph? Finally, to determine a learner's motivation and self-confidence in writing, the IEP team can use informal observations or interviews with the learner.

4.2 The learning task

4.2.1 Measurable IEP goals

Measurable annual IEP goals are designed to meet specific needs of the learner, as identified in the PLAAFP. Specifically, these goals should support the diverse and exceptional learner in achieving

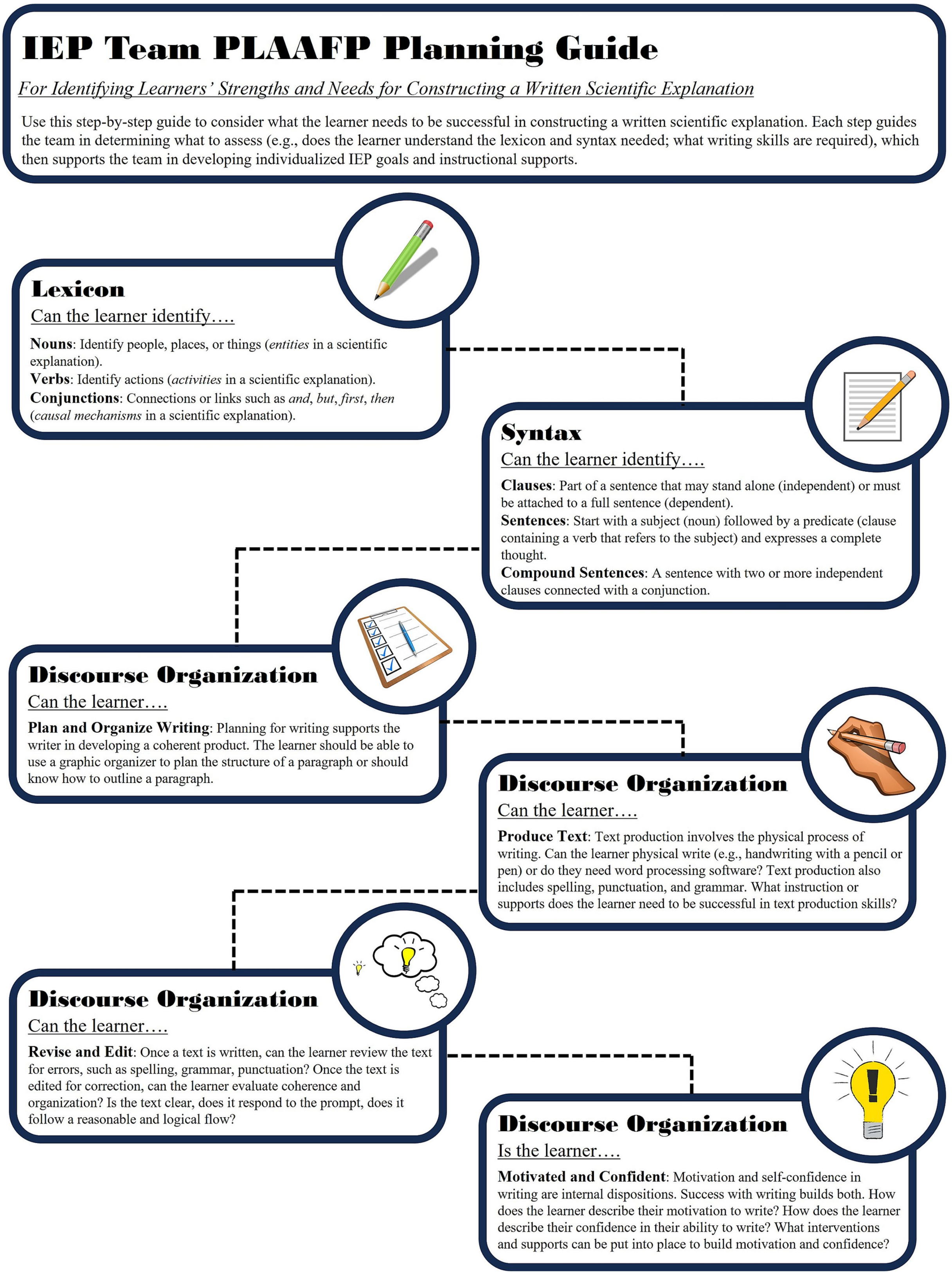

FIGURE 3
IEP team planning guide.

success in the general education curriculum. Based on assessment findings described in the PLAAFP, the IEP team should develop measurable goals related to dialectical structures (e.g., lexicon, syntax, discourse organization) and four writing skills (e.g., planning and organizing, text production, revising and evaluating, motivation and self-confidence). Because constructing a written scientific explanation involves multiple components, educators should consider writing benchmarks to support the process involved, building writing skills and then applying them to science contexts. For example, if the overall IEP goal is to construct a valid written scientific explanation (e.g., By the end of the IEP year, the student will construct a valid written scientific explanation using appropriate and sufficient evidence and connected to a scientific principle with 80% grammatical accuracy.), then realistic benchmarks to achieve this within a year should include steps: constructing a claim using entities and activities, identifying appropriate and sufficient evidence, using science vocabulary learned previously or related to the phenomenon of study, describing the selected evidence in writing, identifying a related scientific principle, applying the principle in writing, evaluating other scientific explanations, providing feedback for other scientific explanations, and evaluating one's own written scientific explanation.

4.2.2 Instruction and support

Instruction and support for guiding diverse and exceptional learners in constructing written scientific explanations must be explicit, with modeling and practice, and ample constructive feedback. While direct instruction should be provided specifically for areas of need identified in the PLAAFP related to dialectical structures and the four writing skills (Gillespie and Graham, 2014), the focus here will be on using a graphic organizer (Graham et al., 2020) to support diverse and exceptional learners in planning and organizing their constructed scientific explanation, writing it, and then evaluating it for effectiveness and accuracy.

The Claim, Evidence, Science Principle graphic organizer (Table 3) divides the task of writing a constructed scientific explanation into parts, each of which must be explicitly introduced to students to explain their significance and purpose in learning science content (Sandoval, 2003; Klein, 2004). When learners understand the purpose of writing, it can be motivating, particularly when educators explain that writing a constructed scientific explanation is a practice engaged in by scientists in the field (National Research Council, 2012). Instruction in writing a claim statement must include explicit teaching and modeling of the parts of a claim statement: entities (nouns), activities (verbs), target phenomena. Students must know that a sentence is a complete statement, with correct capitalization and punctuation, and must know how to use science vocabulary as presented in class. As noted in the graphic organizer, the claim is a statement (sentence) that answers the question that is asked. Learners then need to be explicitly taught to use the evaluation criteria questions to decide if the claim statement addresses the question fully. Instruction in writing evidence statements begins with science content instruction that is much broader than writing. Science educators must provide students with instruction in reading charts and tables, in using models to depict phenomena, and in making and recording their own observations. Then, explicit instruction and modeling will support learners in determining if evidence is appropriate to support the claim statement, and if there is sufficient evidence to make a valid argument. Per the graphic organizer, data (e.g., charts, tables, observations measured with instruments, tools for modeling) should support the claim and be confirmed by others. Learners will need explicit instruction in using causal mechanisms to clarify order that may occur in scientific processes and will need support in ensuring evidence statements are complete sentences. Finally, scientific principles should be explicitly taught, based on science curriculum used in the science classroom. Educators should ensure science principles make sense to students, providing examples that are relevant and meaningful. Principles should be available for learners to use (e.g., in science notebooks, posted in the classroom). Instruction in how to access and cite principles should be explicit and include modeling. The graphic organizer then supports learners in ensuring that the principle they have selected is relevant and supports the claim and evidence statements.

4.3 The learning environment

4.3.1 Collaboration between general and special education teachers

The learning environment for middle- and high-school, diverse and exceptional learners should be in the general education science classroom, with collaboration occurring between the science teacher and the special education teacher. Writing a constructed scientific explanation is a culminating practice following instruction related to the phenomenon of study. In their seminal work on collaboration, Cook and Friend (1995) noted one of the most beneficial collaborative models for all students, particularly for diverse and exceptional students, is co-teaching. While they presented several approaches to consider when co-teaching (e.g., one teaches, one supports; teachers divide up students and each teaches a group), the best approach for supporting students in constructing written scientific explanations is a team approach (Colley and Lassman, 2021). As a team, each partner teachers' expertise should guide instructional planning and delivery. The general education science teacher, having science content knowledge, should support instructional planning and deliver instruction related to science principles and vocabulary. The special education teacher, having reading content knowledge and pedagogical knowledge related to supporting diverse and exceptional learners, should support instructional planning and deliver of explicit instruction in using the graphic organizer (Table 3), which includes modeling as a whole group first. With equal support from both team teachers, students will engage in reading science texts, reviewing and discussing data (e.g., charts, tables), collecting and recording their own data from observations, and modeling phenomena (e.g., drawing, building diagrams, using ball and stick models). While the science

TABLE 3 Claim, evidence, science principle graphic organizer.

	What is this?	Explanation quality criteria
Question	The question to be answered	Does the claim respond to the question?
Evidence	Data that supports the claim and can be confirmed. Data are based on observations that are made with our senses or measured with instruments.	Does the evidence support the claim?
Science principle	Accepted scientific idea, concept, or principle used o show why the evidence supports the claim.	Is the scientific principle selected relevant to the claim? Does the evidence align with the scientific principle?

Adapted from McNeill and Martin (2011) and American Association for the Advancement of Science (2017).

teacher should model what evidence is appropriate and sufficient to address a claim statement, the special education teacher should model how to put the pieces of the constructed response together. Then, as instruction moves into a new phenomenon, students should have practice using the graphic organizer in small groups to create a group constructed scientific explanation. While students are working collaboratively in small groups, both the science teacher and special education teacher should be monitoring their work, supporting them in selecting evidence, providing feedback in writing claim and evidence statements, and helping them select the correct scientific principles to use. In a subsequent lesson, all students should be explicitly taught how to use the evaluation criteria in the graphic organizer to assess explanations written by others. This should include both teachers modeling and leading whole group discussions. Students should then have practice in small groups with writing their own explanations and using the criteria to evaluate what they have written. Then they should be taught how to give feedback to other groups' explanations in whole class discussions. Gradually, students can practice using the graphic organizer to individually write their own constructed scientific explanations, evaluate them, share them in small groups, and provide feedback and support to each other.

4.3.2 Providing accommodations

When in the general education, science classroom, appropriate accommodations make learning science concepts possible for diverse and exceptional learners. Accessing scientific knowledge happens through reading science disciplinary texts, participating in scientific discourse, collecting scientific data, and engaging in the writing practices of the discipline. Proven accommodations and supports for ensuring the active participation and success of diverse and exceptional learners include some of the following: providing guided notes or handouts prior to a lecture (Gin et al., 2020), explicitly teaching scientific principles and ensuring regular access (e.g., posted in the classroom, in a science binder; Russell and Martin, 2023), having students work in small groups to support each other (Vaughn et al., 2011), peer-assisted learning (Fuchs et al., 2020), supports when reading grade level science texts (e.g., audio recorded texts, teacher read aloud; Witmer et al., 2018), and support in physically writing (e.g., dictation, group work; Nightingale et al., 2022).

5 Discussion

The purpose of this conceptual analysis was to examine the constituent elements and connecting structures of constructed scientific explanations, specifically for supporting diverse and exceptional learners. This is valuable because constructing a written scientific explanation engages students in a fundamental science practice that supports the development of more complex scientific knowledge related to better knowing our natural world around us. Furthermore, when diverse and exceptional learners are successful in engaging in the practice of science with their peers, their self-esteem grows and the motivation to learn is accelerated.

The NGSS were designed on the principle that all students, including diverse and exceptional students, are capable of engaging in science practices that support the construction of science literacy, when provided with equitable learning opportunities (NGSS Lead States, 2013). Making that learning accessible will require collaborative efforts between general and special educators. Constructing a valid written scientific explanation is a process which can be daunting for diverse and exceptional learners. However, as noted in this conceptual analysis, the process is a learning progression (Duncan and Hmelo-Silver, 2009) of smaller tasks (e.g., understanding lexicon, using syntax, developing discourse organization) that build in complexity to support deeper understandings of the content examined.

Supporting diverse and exceptional students in mastering the constituent elements and structures of a constructed scientific explanation not only develop disciplinary literacy (Shanahan and Shanahan, 2012) related to the scientific concepts being studied, but support students in acquiring academic literacy skills (Torgesen et al., 2017) which can be applied in other contexts (e.g., writing summaries, position essays, comparing and contrasting evidence). Furthermore, by providing explicit instruction to diverse and exceptional learners on each constituent element (e.g., how to identify entities/nouns and activities/verbs in a claim statement/sentence) that uses structures (e.g., Claim, Evidence, Science Principle Graphic Organizer) to cumulatively build the process of constructing a scientific explanation, all students gain equitable access to learning.

5.1 Limitations and implications

This conceptual analysis and the framework proposed are generalized conceptualizations of how best to support diverse and exceptional learners in engaging meaningfully in middle- and high-school general education, science classrooms. They are not exhaustive or comprehensive as each learner brings unique strengths and needs to the task of constructing a written scientific explanation. Furthermore, middle- and high-school aged students bring diverse experiential knowledge about the natural world with them to the science classroom or may have had differential academic experiences related to science. This complicates learning science and the practices involved in developing science disciplinary literacy. Research in using graphic organizers, such as the one provided here, is in its infancy. Research related to using NGSS in general, and more specifically, with diverse and exceptional learners in general education, science classroom settings, is also emerging. Understanding the impact of frameworks such as ours over time will provide valuable information for middle- and high-school science educators and the special educators who collaborate with them.

There is much yet to learn about how best to support diverse and exceptional learners in engaging equitably in using science practices, such as constructing written scientific explanations. This conceptual analysis provides a clear pathway for general and special educators to universally design instruction in middle- and high-school, general education science classrooms that supports all learners, but most specifically our diverse and exceptional learners. Providing graphic organizers (e.g., Table 3) alone may support many general education students in successfully crafting scientific explanations that support deeper learning of the content. However, diverse and exceptional learners require explicit instruction that builds cumulatively and is supported by practice with immediate feedback on each part of a constructed scientific explanation. Consequently, students learn science, but also develop powerful writing tools in their academic toolkits to use across content areas to become conscientious consumers of knowledge.

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BM: Conceptualization, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing. JW: Resources, Visualization, Writing – review & editing.

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