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Including visual representations within senior high school biology assessment: Considerations of grammatical complexity

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Abstract

This paper analyses the opportunities for presenting knowledge that are created when assessment allows senior high school biology students to draw on linguistic and visual resources when constructing meaning in response to short-answer examination-style questions requiring a sequential explanation. Students within one senior high school biology class were given the opportunity to respond to an examination-style question through both written and visual representations. Analysis of the student responses for high and middle-achieving students, from a systemic functional linguistics perspective, indicates that high-achieving students use a broader range of grammatical forms more often than middle-achieving students to present key understandings of classification and composition within both written and visual representations. Including opportunities within assessment for students to express knowledge through written and visual representations allows for students to elaborate within their short-answer responses and to construct the broader range of representations that is valued within the discipline, but explicit guidance is required to support all students to make use of the complex grammatical patterns within written and visual representation. For senior high school biology students to be successful in the final stages of schooling, explicitness about the complex grammars of visual and written representations is required within curriculum and pedagogy.

INTRODUCTION

Engaging students in visual and linguistic ways of making meaning is an essential part of learning in science. Through learning about the conventions of making meaning within written and visual representations, students will be apprenticed into the discourse of science (Tytler, 2007). In addition, the process of representing knowledge through various modes will support the development of conceptual understanding in the discipline (Ainsworth, 1999; Hubber et al., 2010; Moje, 2008; Tytler, 2007; Tytler et al., 2013) and critical thinking (Gough, 2006). Exposure to varied ways of making meaning within scientific discourse will expand the conceptual content of science education and produce opportunities to consider multiple meanings (Ainsworth, 1999; Gough, 2006). Diagrams will often group together large amounts of information that support immediate problem solving (Larkin & Simon, 1987). Advances in computer science have increased opportunities to represent abstract external representations in science education that can support cognitive understanding (Hegarty, 2004). Movement between multiple representations will enable students to extend understanding of concepts and to enhance problem solving (Ainsworth, 1999).

While both linguistic and visual resources for constructing knowledge are important within science, opportunities for students to engage with both can be limited. Shanahan (2004) argues that the emphasis on practical work in some classrooms has resulted in a decline in the reading and writing of scientific texts. In other classrooms, there may be an emphasis on the reading of a textbook, but explicit teaching on how to read the text is absent, and the students are not encouraged to produce their own texts in a variety of forms (Shanahan, 2004). The textbooks that students encounter are also often limited in the range of textual forms presented (Gough, 2006). Visual and linguistic representations that can provide insight into diverse social meanings and adaptations of science are often not included, and presentations of scientific knowledge remain static and uncritiqued (Gough, 2006). The visual representations that are included usually represent conceptual understandings that come from traditional western cultures and these continue to dominate (Gough, 2006).

While the use of visual representations may remain limited within textbooks, there has been extended use of visual representations through other classroom curriculum materials. Such resources have included forms such as learning software, photographs and recordings (Ainsworth, 1999; Eilam & Ben-Peretz, 2010). Van Rooy and Chan (2017) argue that, while teaching materials in senior high school biology have increasingly included visual representations, such as diagrams and naturalistic depictions, senior high school biology examinations continue to favour written text. Childs and Baird (2020) also demonstrate how high-stakes assessments narrow the ways in which students can represent knowledge in high school science. Van Rooy and Chan (2017) assert that the mismatch between teaching resources and highstakes assessments in the final years of schooling limits the opportunities that students have to demonstrate their knowledge (Van Rooy & Chan, 2017). More generally, Jewitt (2003) demonstrates how technology has provided increased opportunities to learn across the curriculum through multimodal texts that contain visual elements, but assessments are limited to written language. Van Rooy and Chan (2017) suggest that incorporating more opportunities for students to present knowledge through visual representation in senior science examinations will result in more students achieving success because there will be greater alignment between teaching materials and assessment techniques. They argue further that the incorporation of visual representation in examinations will be supportive of students 'whose learning preferences or language background favour non-written modes' (Van Rooy & Chan, 2017, p. 1252).

Limiting the range of ways in which scientific knowledge is represented in school science narrows students' experiences and does little to attend to the decreasing numbers of students taking science subjects. Often students are exposed to visual representations that reflect prevailing discourses within western culture (Gough, 2006). Maintaining dominant discourses about science through limited forms of representation reduces the possibilities for students to perceive science as dynamic with cultural variations (Gough, 2006). In a number of countries there is an ongoing concern about school students' achievement levels and participation in science subjects (Cooper et al., 2018; Dewitt et al., 2014; Murphy, 2020). Extending the opportunities to make meaning through varied textual representations is one way to alter students' experiences of school science and to support greater participation and achievement. The forms of visual representation that could be included within school science range from naturalistic drawings to more abstract diagrams (Martin, 2017). Engaging students to think about concepts through the multiple forms of visual representations will foster critical thinking, creativity and interest (Gough, 2006).

The absence of opportunities for students to express meaning through visual, as well as written forms, in senior school examinations has been clearly documented in the literature (Britton et al., 1996; Childs & Baird, 2020; Jewitt, 2003; Van Rooy & Chan, 2017). These studies suggest that the inclusion of greater opportunities to demonstrate knowledge through visual representations will support students who struggle to express meaning within written responses, and they will have more opportunity to work with their strengths (Britton et al., 1996; Gangwer, 2009; Van Rooy & Chan, 2017), but this suggestion has not been explored. Such advice suggests that the meaning making strategies used for visual representation may be easier and more accessible to some students than the resources required for creating written text.

Martin (2017) and Cheng and Gilbert (2015) suggest that presenting scientific understanding through visual representations is a complicated process that is not easily accessible to students. Constructing knowledge through visual representation often involves distilling large amounts of information from written texts into visual form (Martin, 2017). The condensed meanings are then expressed in visual representations through complex visual grammatical forms (Martin, 2017). Such visuals will often use conventions that are not readily understood by students (Ainsworth, 2006; Cheng & Gilbert, 2015). Similarly, Akaygun and Jones (2014) argue that presenting certain meanings, such as processes, through visual representations in explanations in chemistry and physics can be more difficult than through written text. Ainsworth (1999, 2006) argues that multiple representations can be used to develop deeper conceptual understanding, but only if the ways of making meaning within and between representations are carefully scaffolded for the learners.

Detailed studies of the meaning making resources that students draw on when constructing knowledge through written and visual texts in senior high school biology examinations are now required. Such studies can provide insight into the ways in which students at different levels of achievement utilise these resources and determine if students struggling to achieve with written modes are more able to utilise the ways of making meaning in visual representations. This study provides one such contribution by presenting detailed analyses of the meaning making resources used by students at different levels of achievement when producing written and visual sequential explanations for the processes involved in making proteins (transcription and translation). Transcription involves the first stage of protein synthesis: a gene's DNA is copied to make a messenger RNA molecule. Translation is the second stage where the sequence of a messenger RNA molecule is used to form a sequence of amino acids. The overarching research question for the study is: ‘To what extent are high and middle-achieving students, in senior high school biology classes, able to use meaning making practices to construct knowledge through written and visual texts within examination-style short-answer responses requiring a sequential explanation.’ Within the context of this study, visual representations of processes, such as translation, are also described as a visual text. Within these visual representations, there is the opportunity to provide a stretch of meaning making which can be interpreted as a visual text.

THEORETICAL FRAMEWORK

Science subjects, discourse and curriculum theory

Each discipline area privileges a range of ways to make meaning, which is associated with the 'social purpose and cultural conventions' of the specific discipline (Moje, 2015, p. 255). Collectively, the selected ways in which knowledge is constructed within a specific context forms a discourse (Foucault, 2002 [1969]; Gee & Handford, 2012). Working effectively within a disciplinary context involves understanding and using the meaning making resources that are valued within that discourse community (Moje, 2008, 2015; Shanahan & Shanahan, 2008).

In the discipline area of science, both written and visual representations are essential for the building and communication of knowledge. Latour (1999) argues that the process of doing science involves constructing 'representations' of the world (p. 30). Disciplinary work within science concerns the representation of concepts through a range of modes including visual and written texts (Lemke, 1998; Tytler, 2007; Waldrip & Prain, 2013). Prain and Tytler (2013) argue that it is through the analysis and construction of a broad range of scientific texts that students will gain knowledge and skills related to the 'meaning-making practices of the science community' (p. 9). The visual representations used to make meaning within scientific discourses may range from naturalistic depictions to those that offer a symbolic display (Kosslyn, 1989). For example, the depiction of the DNA double helix may be symbolic with two simple intertwined lines and the base pairs labelled, or there may be a more naturalistic visual representation where the creator's intent is to show what would be seen under an electron microscope. The more abstract depictions use symbolic conventions to communicate within the discourse community (Goodman, 1968; Kosslyn, 1989). For example, within visual representations of the DNA double helix the base pairs may be symbolically represented through two lines that join in the middle and each line is labelled with a letter that represents the kind of base (e.g., 'A' for adenine).

The consideration of school subjects as ways of making meaning within discipline specific discourses is associated with theories of curriculum that prioritise knowledge, rather than the formation of curricula that are solely relative to the lived experiences of the student (Moore & Muller, 1999; Young, 2008, 2014; Young & Muller, 2013). Curriculum that is purely relative to the lives of students removes disciplinary knowledge, and, in turn, limits students' access to forms of knowledge that can afford personal and social benefits (Young, 2013; Young & Muller, 2013). The argument for curricula that contain disciplinary forms of knowledge is particularly relevant for the sciences where there are specific knowledge forms with intricate conventions for presenting meaning (Yates & Millar, 2016; Young & Muller, 2013). Curriculum design, including official documentation, teacher resources and assessments, along with associated pedagogies, should apprentice students into the ways of making meaning within discipline contexts (Moje, 2008, 2015; Rose & Martin, 2012; Shanahan & Shanahan, 2008; Young, 2013). Part of the apprenticeship involves exposing students to and teaching explicitly the textual forms and related meaning making processes inherent to the discipline (Moje, 2015). Without such an apprenticeship, the students are restricted from some of the most powerful forms of knowledge (Rose & Martin, 2012; Young, 2013).

Analysing meaning-making practices through genre theory and systemic functional linguistics

This study uses a social semiotic approach and draws specifically on genre theory. The approach places lexicogrammar at the centre of meaning making (Halliday & Matthiessen, 2014; Martin & Rose, 2008). Meanings are realised within specific discourses through the grammar (language choices) that are made within clauses (Halliday & Matthiessen, 2014). Within any text, patterns of language choices can be identified, which construe the meanings that are made within a specific situation and cultural context (Halliday & Matthiessen, 2014). The grammar of the text functions to achieve discourse meanings and to realise the purpose of the text type (Halliday & Matthiessen, 2014; Martin & Rose, 2007). Within all situations, choices about grammar will be made to realise meanings related to the ideas being presented (ideational meanings), the relationships between participants (interpersonal meanings) and the organisation within the method of communication (textual meanings) (Halliday & Matthiessen, 2014; Martin & Rose, 2007).

The functional model of language, first set out by Michael Halliday (1985), has been used to develop genre theory for education. Working effectively within the discipline contexts of various subject areas involves understanding the specific text types, or genres, that are valued within each discipline (Christie & Misson, 1998; Rose & Martin, 2012). Since the 1990s, researchers have been analysing the structures and language patterns of genres that are typically found within the disciplines taught in schools and universities. Extensive work has been done on the genres found within science generally, and, more recently Hao (2020) has analysed the genres and language patterns of biology as a sub-discipline of science.

Much of the research into the genres of science, and Hao's (2020) work on biology in particular, has focused on the language used to realise meanings about ideas. It is through the ideational meanings that knowledge is built (Hao, 2020; Martin, 1993a; Rose & Martin, 2012; Unsworth, 1997). Meanings realised within genres typically found within science often relate to ideas about classification (Halliday, 1993a; Halliday & Martin, 1993; Hao, 2020; Martin, 1993b; Martin, 2017; Rose & Martin, 2012) and composition (Halliday, 1993a; Halliday & Martin, 1993; Hao, 2020; Martin, 1993b; Martin, 2017; Rose & Martin, 2012). Classification involves taxonomising types of observable entities (things), while composition involves presenting taxonomies of wholes, parts and subparts (Hao, 2020; Martin, 1993b; Martin, 2017; Rose & Martin, 2012).

Kress and van Leeuwen (1990, 1996) show how the functional approach to grammar can be used to analyse the meaning-making practices involved in the creation of visual representations. Various grammatical patterns can be used within visual representations to create ideational, interpersonal and textual meanings (Kress & van Leeuwen, 2006). Such grammatical patterns differ from those within written texts, but the meanings being created can be the same (Kress & van Leeuwen, 2006). As in written texts, some of the grammar of visual representations will construe ideational meanings about composition and classification (Kress & van Leeuwen, 2006). Martin (2017) similarly has demonstrated how visual representations, with accompanying written labels, will often be used to provide ideas about classification and composition. More broadly, in the field of visual studies, researchers argue that visual representations contain conventional forms that realise specific meanings. Abstract and symbolic representations will rely on conventions to make certain meanings (Goodman, 1968; Kosslyn, 1989). Through exposure to a broad range of visual representations, students can learn about the conventions of symbols and the meanings associated with them within the specific discourse of science.

This study sought to analyse the meaning-making strategies, otherwise referred to as grammatical forms or resources, used by high-achieving and middle-achieving students to present understanding through visual and written representations within senior school biology. While the overarching research question was, 'To what extent are high and middle achieving students, in senior high school biology classes, able to use meaning making practices to construct knowledge through written and visual texts within examination-style short-answer responses requiring sequential explanations', the following specific research questions also guided the study:

1. What grammatical resources are used by high and middle-achieving senior high school biology students to convey their understanding of classification and composition in short answer examination style responses requiring sequential explanations?
2. How does the range and frequency of grammatical forms vary between high and middle-achieving senior high school biology students when construing meaning about classification and composition?
3. How does the range and frequency of grammatical forms vary between high and middle-achieving senior high school biology students when construing meaning about classification and composition in visual texts that are part of short answer examination style questions requiring sequential explanations?

METHODOLOGY

Multiple case study design is the methodology used within the project. Student created texts, depicting written and visual representations for transcription and translation, were the focus of data collection and analysis. Each student text is treated as one case within the multiple case study design for the project. Selection of multiple cases needs to be based on the central phenomenon for the study (Stake, 2006). In this instance, the selection of the cases allowed for analysis of the meaning-making practices being used by students judged to be at an 'excellent' or 'good' level in senior high school biology. Through the use of multiple case studies, extensive comparisons and contrasts can be made to form rich new knowledge (Khan & VanWynsberghe, 2008). Within this study, the meaning making practices of high and middle-achieving students could be compared and contrasted to generate conclusions about their uses of grammar for visual and written representations. Within science education, student work samples have been used extensively as case studies to reveal the grammatical practices underpinning academic achievement (e.g., Gibbons, 2018; Lo et al., 2018; Schleppegrell, 2004).

Context and participants

The research occurred in a culturally and linguistically diverse metropolitan Australian high school. The participants included students undertaking biology as a subject in their final year of schooling.

Data sources

The student texts were created in response to a short answer practice examination question and were completed under test conditions. The classroom teacher asked the students to complete the task within a double biology lesson. The question asked was: 'Write a sequential explanation of transcription and then draw this process underneath your written explanation. Then write a sequential explanation of translation and draw this process underneath your written explanation.' The students understood from the information letters for the project that they were participating in a study that aimed to find out how they represented knowledge in biology through written and visual text. For this specific task, the teacher told the students prior to them beginning that both their written and visual texts were of equal importance for assessment of the task.

The data analysed include a corpus of four student texts that were identified by the classroom teacher as representative of levels of achievement for the class.

For this study, the particular context and situation are tightly defined. The texts analysed are sequential explanations that have been created within a high school final year biology classroom on the topic of transcription and translation. Given that these texts were created in such a defined situation, it is appropriate that the sample size presented here is small. Rather than searching for a broad range of grammatical resources through many texts, it is more important within genre theory to provide extremely detailed analysis of a small number of texts (Martin & Rose, 2007). The depth of analysis presented here is essential if grammatical choices for meaning making in the particular context are to be revealed. The full written texts completed by the students have been included as Appendix A.

Of the four student texts, two represent those judged by the teacher to be of 'excellent' achievement and two represent those rated as 'good'. The teacher had extensive experience teaching biology in the final year of high school and she had no training in the grammar of written or visual texts. At this stage in the project, no grammatical analyses of written or visual texts had been shared with the teacher. The researchers asked the teacher to assess the student texts using her regular framework for assessment in senior high school biology. For this teacher, this framework was based on the conceptual understanding being presented by the students and it was not based on a grammatical analysis of the texts by the teacher. As a result, the researchers were provided with texts judged by the teacher to be conceptually 'excellent' or 'good'. The researchers then applied grammatical analysis to the texts to interpret the grammatical patterns being used by the students at the different levels of achievement. Comparing and contrasting the texts judged to be 'excellent' and 'good' allowed for conclusions to be reached about the meaning-making practices that are enabling achievement within senior high school biology.

Data collection

At the end of the double lesson, where the students completed their sequential explanations, the teacher collected the work samples, and they were later collected from the school by a researcher involved in the project. De-identification and the application of pseudonyms occurred prior to analysis of the student texts beginning.

Data analysis

Past research into the ways in which conceptual understandings are construed within science, including biology, was used to provide an analytical framework for this study. The framework for analysis, presented in Table 1, was used to analyse the written and visual sequential explanations produced by students. The framework is structured according to the stratified model of language used within systemic functional linguistics. Previous studies in science education have demonstrated that the application of systemic functional linguistics provides a rich framework for analysing the ways in which key meanings are realised through written, as well as visual, representations (e.g., Prain & Tytler, 2013; Tang, 2021; Tytler et al., 2013, 2018). These studies have provided a precedent for analysing written and visual texts through systemic functional linguistics. First, the framework used for analysis in this study presents the notion that key meanings within biology, and especially within sequential explanations, will include classification and composition. Second, the framework outlines some of the main ways these meanings may be realised through the grammar of written text and visual representations.

Halliday (1993b) shows that ideational meanings in science are often realised lexicogrammatically through the noun group, and, sometimes, across a clause. Hao (2020) extends

TABLE 1 Analytical framework for the ways in which ideational meanings are realised within the written and visual sequential explanations

Meaning within the discourse	Realisation of meaning within the written texts	Realisation of meaning within the visual representations
Classification of entities	• A relational process between two nouns/noun groups forming an identifying clause (Halliday, 1993b; Hao, 2020; Martin, 1993a) (e.g., Transcription is the process) • Type of type given within a qualifier in the noun group (Hao, 2020) (e.g., the form of premRNA) • Classifier and thing in the noun group (Hao, 2020; Martin, 1993c) (e.g., RNA polymerase) • Comparative reference in the noun group (Hao, 2020) (e.g., another complementary tRNA)	• Taxonomies may be covert or explicit • Participants presented as subordinate to other participants that are superordinate (Kress & van Leeuwen, 2006) • Chained classification taxonomies with participants interordinate (Kress & van Leeuwen, 2006) • Classifier and thing in the noun group for annotations on drawings (e.g., amino acid)
Composition of entities	• Thing, relational process and circumstance within the clause (Halliday, 1993b) (e.g., the promoter located on a gene) • A relational process between two nouns/noun groups forming an attributive clause (Halliday, 1993b; Hao, 2020; Martin, 1993b) (e.g., the tRNA has an anti codon) • Thing and qualifier in the noun group (Hao, 2020) (e.g., a ribosome within the cytoplasm) • Thing and possessive qualifier in the noun group (Hao, 2020; Martin, 1993c) (e.g., the end of the gene)	• Carrier presented with all relevant identifiable parts (possessive attributes) in an exhaustive visual representation (Kress & van Leeuwen, 2006) • Recursive representation used to depict parts of parts (Kress & van Leeuwen, 2006)

Halliday's (1993b) analysis to demonstrate how the noun group in particular can be used in various ways within biology to construe meanings about classification and composition. For example, the noun group can consist of a classifier and thing to depict type (e.g., RNA polymerase). The last part of the noun group, the qualifier, can be used to indicate when something is part of something else (e.g., the ribosome within the cytoplasm). The various ways in which the clause and the noun group can be used to present ideas about classification and composition within a text are summarised, with examples, in Table 1.

Kress and van Leeuwen (2006) provide ways of analysing classification and composition in visual representations. Classification is achieved when a visual representation presents a participant or participants that are 'subordinate' to another participant (Kress & van Leeuwen, 2006, p. 79). The term 'participant' in this context refers to an entity within the visual representation, such as the DNA double helix. The participant that is not subordinate can be called the 'Superordinate' (Kress & van Leeuwen, 2006, p. 79). Sometimes the subordinate participants are represented without the superordinate participant being presented, which produces a 'Covert Taxonomy' (Kress & van Leeuwen, 2006, p. 79). When the superordinate is presented, an 'explicit' taxonomy is produced (Kress & van Leeuwen, 2006, p. 80). A vertical structure to the visual representation is used to present the classification involved, with the superordinate being placed at the top or bottom of the visual representation (Kress & van Leeuwen, 2006). For example, the student's visual representation of transcription in Figure 1 provides an explicit taxonomy for RNA, with matured mRNA superordinate at the bottom and pre-mRNA subordinate in the middle. Sometimes the classification taxonomy being presented will be 'chained' and the participants involved can be both subordinate and superordinate (Kress & van Leeuwen, 2006, p. 80). The participants which have these interchanging roles are termed '*Interordinate*' [emphasis in the original] (Kress & van Leeuwen, 2006, p. 80). Figure 1 is not an example of chaining as the pre-mRNA does not become superordinate for another subordinate type of mRNA.

Composition within visual visual representations is achieved when a 'carrier', representing the whole structure, is presented with identifiable parts (Kress & van Leeuwen, 2006, p. 87). These parts are the 'possessive attributes' of the carrier (Kress & van Leeuwen, 2006, p. 87). If the visual representation presents parts, but the carrier, or whole, is not presented, then the visual representation is '*unstructured*' [emphasis in original] (Kress & van Leeuwen, 2006, p. 92). If all the parts of a carrier are presented, the visual representation is '*exhaustive*', while if only some parts are present the visual representation is '*inclusive*' [emphasis in original] (Kress & van Leeuwen, 2006, p. 95). In Figure 1 the depiction of pre-mRNA is exhaustive as all the possessive attributes or parts are presented including the introns, exons and poly A tail. Figure 2 is also exhaustive as all parts are presented, such as the anticodon of the tRNA and the codon of the mRNA. If a possessive attribute then becomes a carrier of other possessive attributes, then the visual representation is '*recursive*' [emphasis in the original] (Kress & van Leeuwen, 2006, p. 96). The student drawing of transcription in Figure 1 is recursive as the single stranded pre mRNA is presented first as part of a gene and it then becomes a carrier for introns, exons and a poly A tail.

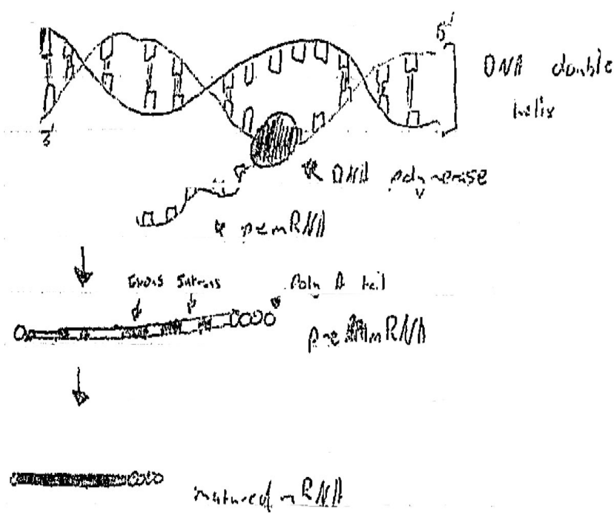

FIGURE 1 Explicit taxonomy for RNA.

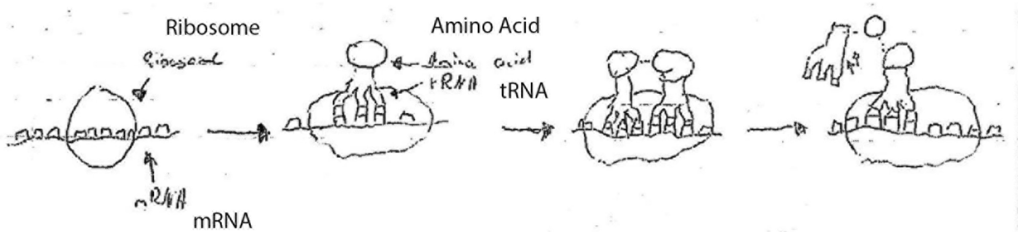

FIGURE 2 An exhaustive representation of translation with carriers and parts.

The work of Kress and van Leeuwen (2006) builds on the earlier work of Larkin and Simon (1987). Larkin and Simon (1987) argue that the benefit of diagrams in science are that they provide information about relationships that are immediately computational. Meaning is made by placing components of a diagram next to each other and producing relationships (Larkin & Simon, 1987). Well-produced diagrams, that effectively depict relationships between components, can afford rapid computation and immediate inference (Larkin & Simon, 1987).

The framework allowed for analyses to be made of the ways in which the students were presenting meaning about classification and composition, the extent of variety in their methods and the frequency with which they used the methods. An example of how the framework for analysis has been applied to a complete student text, including written and visual representation, has been included as Appendix B.

Trustworthiness of analysis

One researcher first used the framework to analyse the four student texts. During analysis the framework provided in Table 1 was completed. A second researcher then also used the framework to analyse the student texts. Consensus was then reached between the two researchers. An example of a complete analysis of a student's written and visual representations once consensus was reached is provided in Appendix B.

RESULTS

Classifying entities

The two high-achieving students, Adnan and Uri, present a large amount of knowledge about the classification of observable entities within both the written and visual representations. Within the written texts, they use the noun group in a range of ways to provide information about the types of entities involved in transcription and translation. They also use these methods multiple times within their texts. Their use of the noun group to classify entities is summarised in Table 2. Classification within the noun group often involves more than one word. The use of classification within the qualifier of the noun group in the example below involves classifying within a phrase beginning with ‘of’. For example, the qualifier ‘of amino acids’ includes the classification of acids to be amino acids. In the examples below the classifier has been bolded to distinguish from the thing in the noun group.

TABLE 2 Analysis of the use of the noun group to classify by Adnan and Uri

Use of the noun group to classify	Uri's written text	Adnan's written text
• Type of type provided within the qualifier	The order of amino acids, the primary level of protein structure	The form of mRNA, the form of premRNA
• Classifiers and thing in the noun group	RNA polymerase, DNA, template strand, RNA nucleotides, mRNA strand, mRNA, tRNA, amino acids, anti codon	DNA, RNA, mRNA, RNA polymerase, tRNA, RNA strand, mRNA strand, amino acids, peptide bond, polypeptide chain
• Comparative reference in the noun group	Complementary RNA nucleotides, complementary single mRNA strand, complementary pair	Another complementary tRNA

At times, classification is automatically included within the abbreviations for entities that the students are using (e.g., DNA). Adnan and Uri also actively create noun groups that provide specific information about the types of entities (e.g., template strand, polypeptide chain). Through their extensive use of classification, Adnan and Uri create taxonomies of classification. For example, different types of RNA are presented.

Adnan and Uri also use the noun group within their annotations on the visual representations to provide information about classification. Adnan presents annotations that include the noun group alone (e.g., DNA double helix), while Uri's annotations often include the noun group as part of a clause (e.g., amino acid chain grows). On one occasion, Uri uses nominalisation to turn a description of a process within the written text into a new nominal group that she then uses as a label on the visual representation of translation. The two clauses ‘the tRNA has an anti codon which is complementary to the codon of the mRNA’ are turned into the classifying noun group ‘complementary base pairing’ on the visual representation of translation. Uri had access to this classifying noun group during the teaching of the topic. In the case of both Adnan and Uri, the predominant way of presenting classification within the annotations is through the use of classifiers within the noun group. The classifying noun groups used by Uri and Adnan within their annotations are presented in Table 3. The classifier has been bolded to distinguish from the thing in the noun group.

Adnan also represents classification through the visual representations themselves. Adnan presents a detailed covert taxonomy for nucleic acid in his visual representation of transcription. Nucleic acid is not presented as superordinate, but a number of types of nucleic acid are depicted including DNA, pre-mRNA and mRNA. These types of nucleic acid were also referred to in Adnan's writing (refer back to Table 2). Adnan also depicts an explicit taxonomy for RNA: matured mRNA is a superordinate at the bottom of his visual representation of transcription, with pre-mRNA being a subordinate type (Figure 3). Uri does not present concepts of classification through her drawing of transcription (Figure 4). Uri's drawing does not present types of nucleic acid. The DNA double helix is presented, but pre-mRNA and mRNA are not. There is also no presentation of an explicit taxonomy for types of RNA. While one of the high-achieving students, Adnan, used grammatical resources effectively to present classification in both written and visual text, the other high-achieving student, Uri, did this within a written text, but not within the visual representation.

In contrast to the high achieving students, the middle-achieving students, Lwin and Linh, do not use all the methods available in the noun group to classify entities and they make little use of the various methods used by Adnan and Uri in both the written and visual representations. Within their written texts, Lwin and Linh mostly use classifiers within the noun group (e.g., RNA polymerase) but they do not use this as extensively as the high-achieving students. They do not make use of the qualifier of the noun group to present information about the type of type. In contrast, the high-achieving students do this extensively in written text. The middle-achieving students also make little use of comparative reference in the noun group to

TABLE 3 Analysis of the use of the noun group to classify by Adnan and Uri within their annotations

Use of the noun group to classify	Examples of annotations from Uri's visual representations	Examples of annotations from Adnan's visual representations
• Type of type provided within the qualifier	None	None
• Classifiers and thing in the noun group	RNA polymerase, amino acid chain, anticodon, mRNA, tRNA	DNA double helix, RNA polymerase, mRNA, Poly A tail, amino acid
• Comparative reference in the noun group	Complementary base pairing	None

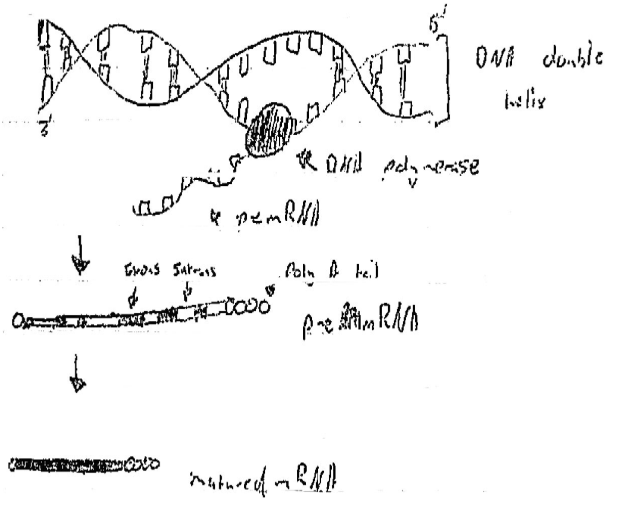

FIGURE 3 Adnan's drawing of transcription.

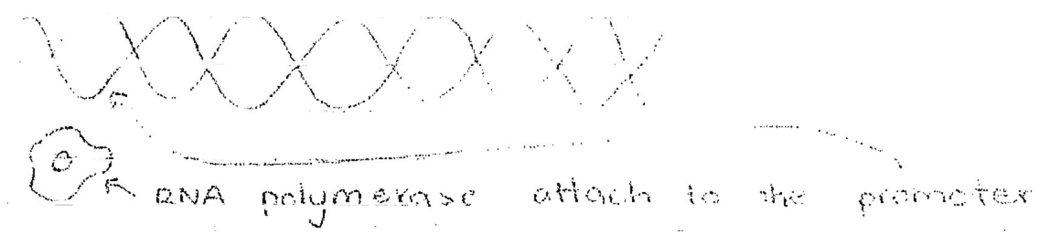

FIGURE 4 Uri's drawing of transcription.

TABLE 4 Analysis of the use of the noun group to classify in Lwin and Linh's written texts

Use of the noun group to classify	Examples from Lwin's written text	Examples from Linh's written text
• Type of type provided within the qualifier	None	None
• Classifiers and thing in the noun group	RNA polymerase, 3 end, template strand, DNA, coding strand	RNA polymerase, 3-to 5 strand, DNA, stop codon, mRNA, tRNA, anticodon
• Comparative reference in the noun group	None	Complementary DNA strand

describe the types of things. Use of the noun group to classify for these two middle-achieving students is summarised in Table 4.

Lwin and Linh make little use of the annotations on their visual representations to present knowledge about classification. Both students only use the grammar of a classifier and thing in the noun group and they use this much less than the high-achieving students. Lwin labels ‘RNA polymerase’, while Linh labels ‘mRNA’ and ‘stop sequence’. In contrast, Uri provides information about classification through her annotations. She does this through using the noun group within a clause and also through nominalisation to create the classifying noun group ‘complementary base pairing’. Lwin and Linh also provide little meaning related to classification through their drawings. Linh depicts to a limited extent a covert taxonomy related to nucleic acid, through the representation of DNA and pre-mRNA. She does not present an explicit taxonomy related to RNA in the drawing of transcription (Figure 5), unlike Adnan who presents the explicit taxonomy of pre-mRNA and matured mRNA (Figure 3). Lwin does not present classification through his drawing of transcription (Figure 6). Types of nucleic acid are not presented and there is no explicit taxonomy for pre-mRNA and matured mRNA. Both of the middle-achieving students struggle to represent understandings of classification in both written and visual text.

Overall, the two high-achieving students presented more meaning about classification within their written and visual texts than the two middle-achieving students. Adnan and Uri were able to use more of the conventions related to the expression of classification within visual and written modes when compared with Linh and Lwin. Such conventions used by Adnan and Uri included the use of the noun group in a range of ways and multiple times within their written texts to depict the types of participants in transcription and translation. Both students also used the noun group effectively within the annotations for their visual

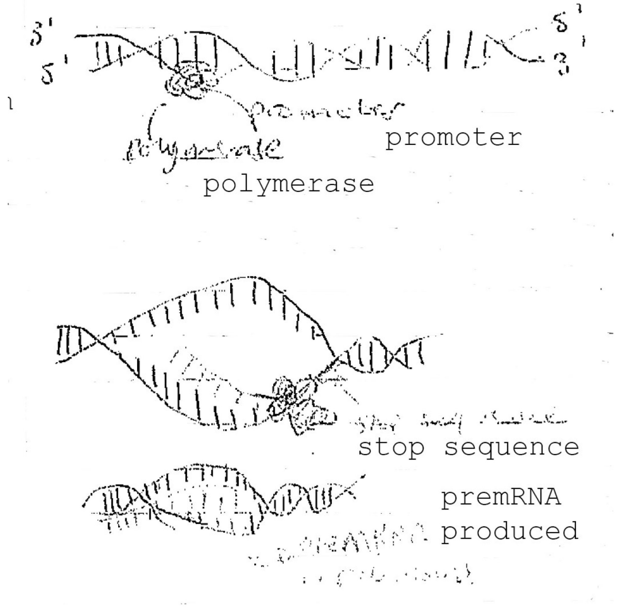

FIGURE 5 Linh's drawing of transcription.

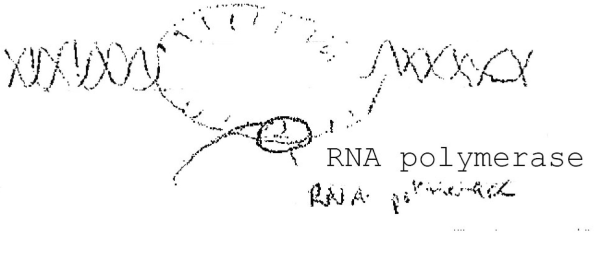

FIGURE 6 Lwin's drawing of transcription.

representations. In addition, Adnan presented explicit and covert taxonomies within his visual representations.

Composition

Within their written texts, the two high-achieving students, Adnan and Uri, use the noun group in a variety of ways (e.g., the end of the gene), as well as clauses (e.g., the tRNA has an anti codon), to present information about entities and their parts. In contrast, the two middle-achieving students, Lwin and Linh, do not use the noun group in a variety of ways or clauses to present knowledge about composition within their written texts. The presentation of composition within the written texts of the four students is summarised in Table 5.

The high-achieving students were able to move from wholes to parts using structures within the noun group, as well as the clause. In contrast, Lwin and Linh only used the noun group.

The two high-achieving students also present more knowledge of composition within their visual representations when compared with the middle-achieving students. Adnan presents information about composition that is not included within his written text. Through his visual representations and annotations, he demonstrates that the DNA is made up of a double helix and a five end, and that the pre mRNA is made up of introns and a poly A tail (Figure 3). Within his visual representations, Adnan also presents details about composition that have been included within his written text. The single stranded pre mRNA is drawn as part of the gene; the exons are drawn as part of the pre mRNA (Figure 3); the anticodon of the tRNA is depicted, as is the codon of the mRNA (Figure 7). As a result of the detailed depiction of parts, Adnan has produced an exhaustive visual representation for the topic. The visual representation produced by Adnan of transcription is also recursive. The single stranded pre mRNA is presented initially as part of a gene. The mRNA then becomes a carrier for introns, exons and a poly A tail (Figure 3).

TABLE 5 Analysis of composition presented within the students' written texts

Use of grammar to construe composition	Adnan's written text	Uri's written text	Lwin's written text	Linh's written text
• Thing, relational process and circumstance within the clause	The promoter located on a gene	None	None	None
• Thing, relational process and thing within the clause	None	The tRNA has an anti codon	None	None
• Thing and qualifier structure	A gene in an anti-sense strand	None	The promoter on the 3 end	None
• Thing and possessive qualifier structure	The end of the gene, a single stranded premRNA of the gene, the nucleus of a cell, the anticodon of the tRNA, the codon of the mRNA, the exons of the strand	The promoter of a gene, the codon of the mRNA	The 3 end of the template strand	The promoter of the 3-to 5 stand

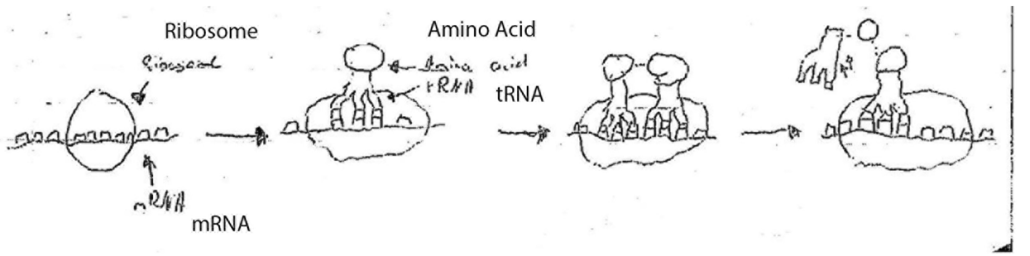

FIGURE 7 Adnan's drawing of translation.

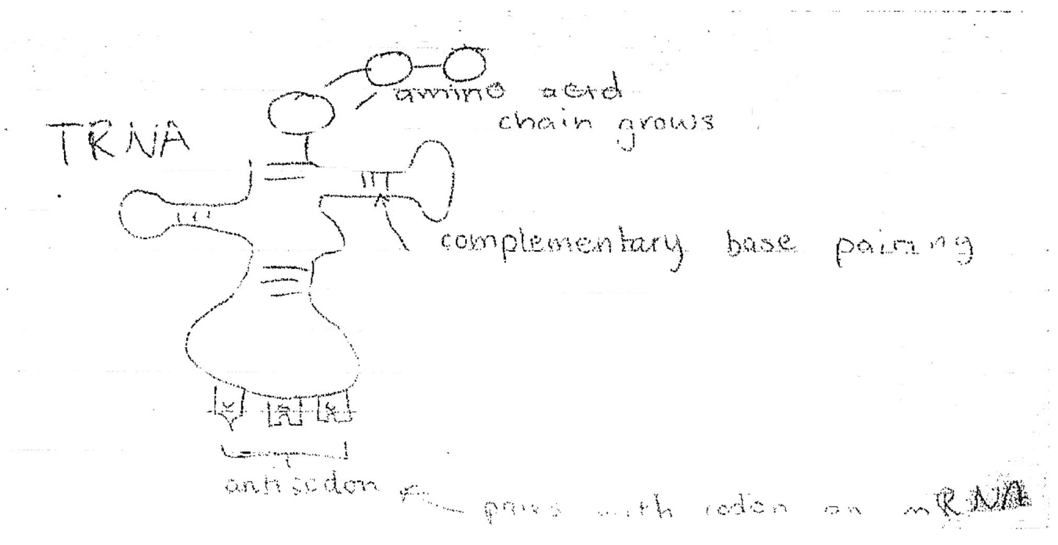

FIGURE 8 Uri's drawing of translation.

The other high-achieving student, Uri, does not present a lot more composition through her visual representations. She does present the DNA as made up of a double helix, which was not in her written text, but, other than that, there is no additional composition within the visual representations (Figures 4 and 8). Like Adnan, Uri does demonstrate composition through her drawing and annotations that has been included within her written text. The promoter is indicated to be part of the DNA (Figure 4); the amino acid chain is made up of amino acids; the tRNA has an anticodon and an annotation explains that the codon that pairs with the anticodon is on the mRNA (Figure 8). Unlike Adnan, the visual representation of transcription produced by Uri is not recursive (Figure 4).

Through the use of drawings with annotations, Adnan and Uri clearly present composition within their visual representations. The middle-achieving student, Linh, presents some composition within her visual representations for transcription. The DNA is shown to be made up of a double helix, with three and five ends and a promoter (Figure 5). There is no composition depicted for translation. The tRNA is drawn, but there is no depiction of the anticodon. Similarly, the codon is not depicted on the mRNA (Figure 9).

Linh does not produce a recursive representation of transcription (Figure 5). In contrast, Adnan does do this by showing how the single stranded pre mRNA is presented initially as part of a gene and the mRNA then becomes a carrier for introns, exons and a poly A tail (Figure 3). These two visual representations have been placed togther below for ease of comparison. Adnan's drawing is first followed by Linh's (Figure 10).

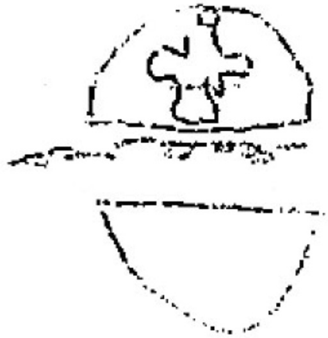

FIGURE 9 Linh's drawing of translation.

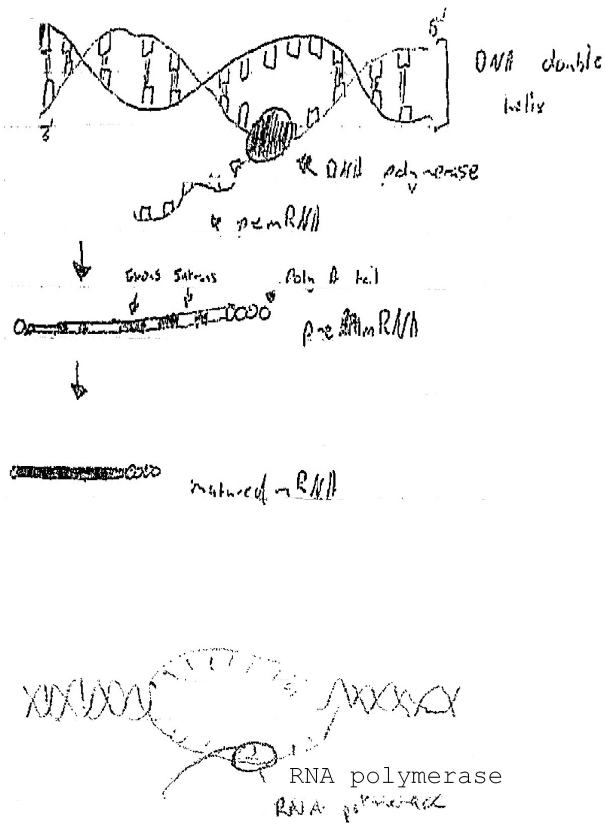

FIGURE 10 Adnan's recursive visual representation of transcription compared with Linh's nonrecursive visual representation.

The other middle-achieving student, Lwin, presents even less composition within the visual representations than Linh. The DNA is drawn as being made of a double helix, but no parts of the DNA are depicted or labelled (Figure 6). The tRNA is not shown to have an anticodon and the mRNA is not depicted as having a codon (Figure 11). Lwin does not produce a recursive representation of transcription (Figure 6).

FIGURE 11 Lwin's drawing of translation.

TABLE 6 Analysis of composition presented within the students' visual texts

Use of grammar to construe composition	Adnan's visual text	Uri's visual text	Lwin's visual text	Linh's visual text
• Exhaustive visual representation	DNA composed of double helix and 5 end Pre mRNA composed of introns and a poly A tail Single stranded pre mRNA as part of a gene Exons as part of the pre mRNA The anticodon as part of tRNA The codon as part of mRNA	DNA composed of double helix Promoter as part of DNA The amino acid chain made up of amino acids tRNA has an anticodon mRNA has a codon	DNA composed of double helix	DNA composed of double helix Promoter as part of DNA DNA has 3 and 5 ends
• Recursive visual representation	Single stranded pre mRNA presented first as part of the gene and then the mRNA is a carrier for introns, exons and the poly A tail	None	None	None

Overall, the high-achieving students draw on more grammatical resources for depicting composition within written and visual representations than the middle-achieving students. A summary table has been included here to clarify the differences between the two groups of students for the visual representations (Table 6).

DISCUSSION

Claims have been made that students who struggle to present understanding through written texts will be able to do so through visual representation (e.g., Britton et al., 1996;

Gangwer, 2009; Van Rooy & Chan, 2017). The findings presented here suggest that students who are struggling to depict meaning within written texts will also find it difficult to draw on the meaning-making resources required to present knowledge in visual representations. Meanings related to classification (taxonomising types of observable entities) (Halliday, 1993a; Halliday & Martin, 1993; Hao, 2020; Martin, 1993b; Rose & Martin, 2012) and composition (taxonomies of wholes, part and subparts) (Halliday, 1993a; Halliday & Martin, 1993; Hao, 2020; Martin, 1993b; Rose & Martin, 2012) are extremely important within the discourse of science and especially within sequential explanations in biology, but the strategies used to make these meanings within written and visual texts are not the same and the grammar of visual representations is as intricate as the grammar of written texts (Cheng & Gilbert, 2015; Kosslyn, 1989; Kress & van Leeuwen, 2006; Larkin & Simon, 1987; Martin, 2017). As visual texts become more abstract, conventions are increasingly used that need to be carefully scaffolded for students (Ainsworth, 1999, 2006; Cheng & Gilbert, 2015).

Working successfully within school science involves understanding and using the meaning-making conventions of the discourse community (Moje, 2008, 2015; Shanahan & Shanahan, 2008). Disciplinary work within science cannot be done unless students have opportunities to analyse and construct a broad range of representations including those that are abstract (Prain & Tytler, 2013; Tytler, 2007). Such opportunities are vital if students are to engage with curricula that prioritise specialist forms of knowledge (Moore & Muller, 1999; Young, 2008, 2014; Young & Muller, 2013).

The results of this study indicate that high-achieving students use a greater variety of grammatical forms to express key meanings about composition and classification more often than middle-achieving students. Explicitness in curriculum and teaching are required to support senior high school biology students to develop ways to interpret and express key meanings within visual representations and written texts. Without such support, some students cannot access essential meaning-making practices for expressing knowledge in science. For example, in this study, the middle-achieving students could not use a variety of ways to present meanings about composition and classification in written and visual representiatons. They made less use of the parts of the noun group than the high-achieving students, rarely used the clause, did not present explicit and covert taxonomies through visual representeations and did not produce exhaustive and recursive visual representations.

When presenting meanings related to classification in written text, the high-achieving students used the noun group in three different ways, within their written sequential explanations, and they often used these methods multiple times. In contrast, the middle-achieving students mostly only used one way to present classification in the noun group (classifier and thing) and they did not use this technique as often as the high-achieving students. Similarly, the high-achieving students were able to use the noun group effectively to classify within their annotations on visual representations, while the middle-achieving students struggled to do this.

Curriculum and related materials need to provide explicit guidance about the kinds of grammatical resources that students need to utilise to express meaning successfully in senior high school biology. Teachers could then draw on this information to model the ways in which the noun group can be used to represent classification. Such modelling could begin by demonstrating how the inclusion of a classifier next to the noun is the most common way of presenting information about types of entities in biology (e.g., RNA nucleotides). The teacher could then demonstrate how the noun group can be expanded to include a comparative reference, which also provides additional information about type (e.g., complementary RNA nucleotides). Finally, the teacher could model how information about type can also be included within the qualifier of the noun group (e.g., the order of amino acids). Through such explicit teaching, the students can gain understanding of how to pack the noun group with information about the classification of entities. Students can then present precise and concise information about classification within their written texts, as well as their annotations on visual representations.

Explicitness within curriculum, resources and teaching about how to present classification within visual visual representations is also required. Only one high-achieving student was able to present classification clearly within his visual representation of transcription. Curriculum materials could support the teacher to provide students with examples of covert and explicit taxonomies within visual representations and to point out how the superordinate entity is presented at either the top or bottom of visual representations representing explicit taxonomies. The teacher could then clarify for students the kind of taxonomy that is required when visually representing classification within a particular topic.

When presenting composition in written sequential explanations, the high-achieving students moved from wholes to parts using structures within the noun group, as well as the clause. In contrast, the middle-achieving students only used the noun group to present composition and their use of the noun group to do this was limited. Both high-achieving students also included a lot of meaning within their visual representations by depicting whole entities with their parts, while the middle-achieving students did this to a much lesser extent. One high-achieving student also depicted more information about composition within his visual representations, than was included within his written text, through the use of exhaustive visual representations. This student also indicated when a visual representation was recursive and an initial part in one section became a carrier of parts in the next section of the visual representation.

Explicit curriculum resources and teaching of the ways to depict composition within written and visual texts would support student achievement. Teachers could model for students how composition is concisely achieved through the noun group, especially by using a possessive qualifier beginning with 'of' (e.g., the anticodon of the tRNA). They could also demonstrate how the clause, with a relational process, can be used to depict composition by relating two things (e.g., the tRNA has an anti codon) or by relating a thing to a circumstance (e.g., the promoter located on a gene). Explicit resources and teaching related to visual representation could include an emphasis on depicting parts within wholes, as well as indicating when a part of a whole needed to become recursive.

Van Rooy and Chan (2017) assert that student achievement in school biology is being limited because the visual texts being used by teachers in their classrooms are not represented within high-stakes assessment tasks. They suggest that the inclusion of more opportunities to present knowledge through visual representation will improve achievement (Van Rooy & Chan, 2017). The findings of this study indicate the inclusion of visual representation opportunities within examination style short answer responses requiring the creation of sequential explanations does not result in greater achievement for those students struggling with the representation of understanding through written texts. The middle-achieving students used fewer meaning making strategies within both visual and written texts when compared with the high-achieving students. One of the high-achieving students in this study also struggled to make key meanings through her visual representations and she had a greater repertoire of practices to draw on for her written text. The findings support the work of Ainsworth (1999) who argues that the affordances of using multiple representations will only be achieved in learning environments when the elements of representations are carefully scaffolded.

The findings indicate that the presence of visual representations in classrooms, along with changes to assessment, will not support student achievement and that explicit support about the meaning making strategies being used within visual representations, as well as written texts, is required. This study is however limited to the production of written and visual texts in the form of sequential explanations in one topic of biology. More studies are now required to determine if these findings are relevant in other genres, subdisciplines of science and specific topics. Research in functional grammar over a number of decades suggests that the representation of ideas in science is often concerned with classification and composition, and that these elements of ideational meaning making are relevant across science subdisciplines and genres. It is therefore possible that the findings of this study could be generalised to some extent.

High-stakes examination contexts often value written responses rather than responses provided through visual representations (Britton et al., 1996; Van Rooy & Chan, 2017). The findings of this study indicate that key understandings within senior high school biology can be represented through both written texts and drawings, which means that visual representations can also be used as assessment tools. Working as a scientist involves being able to represent knowledge through a range of modes (Lemke, 1998; Tytler, 2007; Waldrip & Prain, 2013). Broadening examination questions to include more opportunities for students to respond through visual representation would allow senior high school biology students to engage more with valued disciplinary practices. Assumptions cannot be made though that students will know how to represent knowledge through visual representations and explicit teaching of this, along with the grammatical patterns of written texts, is essential. Given the complexity of the grammatical forms, curriculum should provide teachers and students with opportunities to focus on the grammars of written and visual representations throughout high school.

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CONFLICT OF INTEREST

The authors declare there is no known conflicts of interest with respect to this research, authorship, and publication.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

ETHICS STATEMENT

Ethics approval was granted by the Australian Catholic University Ethics Committee.

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APPENDIX A: STUDENTS' WRITTEN TEXTS

Adnan's written text

Transcription

Transcription is the process by which DNA is copied in the form of mRNA. This happens in a number of steps. Firstly, RNA polymerase attaches to the promoter located on a gene in an anti-sense strand. From there the polymerase works towards the 5′ end mapping it and copying the DNA in the form of premRNA. The polymerase detaches at the end of the gene and now a single stranded premRNA of the gene is complete. From here, the introns are cut out leaving only the exons of the strand left. Matured mRNA is produced from transcription and all the steps occur within the nucleus of a cell.

Translation: Next the completed RNA strand leaves the nucleus and finds a ribosome within the cytoplasm. The ribosome locks the RNA in place from the 5′ end whilst tRNA carry amino acids to the ribosome. If the anticodon of the tRNA is complementary to the codon of the mRNA then the tRNA attaches to the mRNA strand. Then another complementary tRNA comes along next to the previous acid the two amino acids, side by side form a peptide bond. The ribosome moves the mRNA along until a stop codon is reached. The now fully developed polypeptide chain is then released from the ribosome.

Uri's written text

Transcription

RNA polymerase attach to the promoter of a gene and unwind the DNA along the template strand. Complementary RNA nucleotides join creating a complementary single mRNA strand this is a pre mRNA strand. Introns are spliced out, exons join together to form a mature mRNA strand.

Translation

The mRNA moves from the nucleus to the cytosol where it attaches to a ribosome providing instructions on the order of amino acids.

tRNA brings amino acids to the ribosome the tRNA has an anti codon which is complementary to the codon of the mRNA. The amino acid that the complementary pair code for is added to the growing polypeptide, which when completed is the primary level of protein structure.

Linh's written text

Transcription

The RNA polymerase attaches itself to the promoter of the 3 – to 5 strand.

It unwinds the DNA by moving along the strand to create a complementary DNA strand. When it reaches a stop codon the mRNA disconnects from DNA rewinds with the pre mRNA produced.

Translation: The MRNA [the student originally wrote polypeptide chain but crossed this out and wrote 'mRNA' above] goes into the ribosome and the tRNA matches up with the anticodon.

Lwin's written text

Transcription

The RNA polymerase attaches to the promoter on the 3 end of the template strand. It then unzips the DNA and makes a strand complementary to the template strand meaning it makes a copy of the coding strand.

APPENDIX B: COMPLETE ANALYSIS OF WRITTEN AND VISUAL TEXTS FOR ADNAN

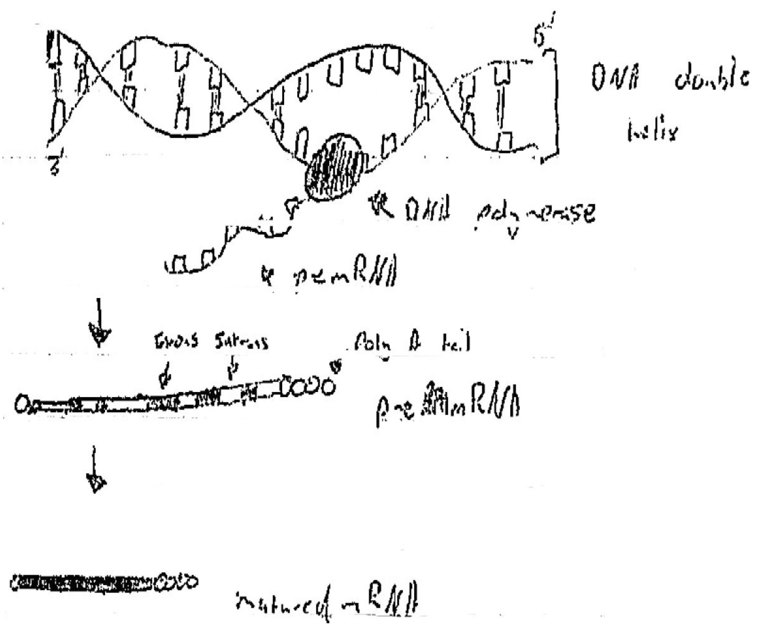
Adnan's written text

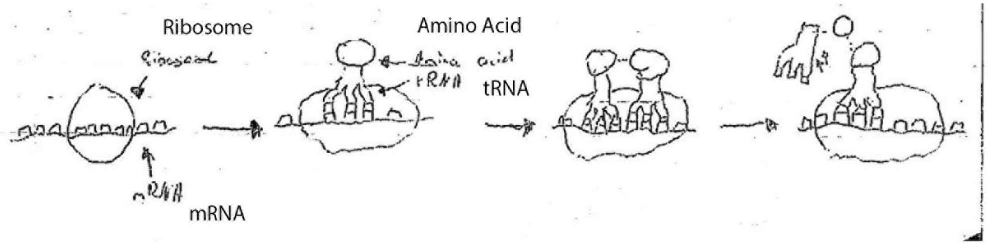
Transcription

Transcription is the process by which DNA is copied in the form of mRNA. This happens in a number of steps. Firstly, RNA polymerase attaches to the promoter located on a gene in an anti-sense strand. From there the polymerase works towards the 5′ end mapping it and copying the DNA in the form of premRNA. The polymerase detaches at the end of the gene and now a single stranded premRNA of the gene is complete. From here, the introns are cut out leaving only the exons of the strand left. Matured mRNA is produced from transcription and all the steps occur within the nucleus of a cell.

Translation: Next the completed RNA strand leaves the nucleus and finds a ribosome within the cytoplasm. The ribosome locks the RNA in place from the 5′ end whilst tRNA carry amino acids to the ribosome. If the anticodon of the tRNA is complementary to the codon of the mRNA then the tRNA attaches to the mRNA strand. Then another complementary tRNA comes along next to the previous acid the two amino acids, side by side form a peptide bond. The ribosome moves the mRNA along until a stop codon is reached. The now fully developed polypeptide chain is then released from the ribosome.

Adnan's visual texts for transcription and translation.





Analysis of Adnan's texts

(The description of the grammar is provided first followed by the evidence from Adnan's texts)

Meaning within the discourse	Realisation of meaning within Adnan's written text	Realisation of meaning within Adnan's visual representations
Classification of entities	• A relational process between two nouns/noun groups forming an identifying clause: None • Type of type given within a qualifier in the noun group: the form of mRNA, the form of premRNA • Classifier and thing in the noun group: DNA, RNA, mRNA, RNA polymerase, tRNA, RNA strand, mRNA strand, amino acids, peptide bond, polypeptide chain • Comparative reference in the noun group: another complementary tRNA	• Taxonomies may be covert or explicit: covert taxonomy for nucleic acid and explicit taxonomy for RNA • Participants presented as subordinate to other participants that are superordinate: matured mRNA superordinate at bottom of visual representation of transcription, with pre-mRNA a subordinate type • Chained classification taxonomies with participants interordinate: None • Classifier and thing in the noun group for annotations on drawings: DNA double helix, RNA polymerase, mRNA, Poly A tail, amino acid
Composition of entities	• Thing, relational process and circumstance within the clause: the promoter located on a gene • A relational process between two nouns/noun groups forming an attributive clause: none • Thing and qualifier in the noun group: a gene in an anti-sense strand • Thing and possessive qualifier in the noun group: the end of the gene, a single stranded premRNA of the gene, the nucleus of a cell, the anticodon of the tRNA, the codon of the mRNA, the exons of the strand	• Carrier presented with all relevant identifiable parts (possessive attributes) in an exhaustive visual representation: Exhaustive visual representation of transcription—DNA with a double helix and a five end, pre-mRNA as part of the gene and exons, introns and poly A tail as part of pre-mRNA. Exhaustive visual representation of translation—tRNA with anticodon, mRNA with codon • Recursive representation used to depict parts of parts: single stranded pre mRNA presented initially as part of a gene—then the mRNA becomes a carrier for introns, exons and a poly A tail