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Published in:
International Journal of Science and Mathematics Education

DOI:
10.1007/s10763-023-10405-7

2023

International Journal of Science and Mathematics Education
https://doi.org/10.1007/s10763-023-10405-7

The Role of Scientific Language Use and Achievement Level in Student Sensemaking

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Received: 13 October 2022 / Accepted: 12 June 2023

Abstract
Many science students struggle with using scientific language and making sense of scientific phenomena. Thus, there is an increased interest in science education research and public policy with regard to understanding and promoting scientific language use and sensemaking in science classrooms. However, there is a lack of comparative studies on how upper-secondary school students of different achievement and language levels use scientific language to make sense of phenomena. The aim of this study was to explore the relationship between achievement level, scientific language use, and sensemaking in chemistry for students being set a sensemaking task while constructing concept maps on the topic of chemical equilibrium. The concept maps were collected from five different upper-secondary schools in Sweden from two school systems (Swedish and International Baccalaureate). Using content analysis, these concept maps were examined for scientific language use as well as structuring of sensemaking. A majority of the students had difficulty structuring sensemaking in their concept maps, independently of achievement level. These difficulties included unstructured reasoning, symbolic representations being used as explanations, surface-level learning, and linear reasoning connected to rote learning. There appeared to be a connection between learning context and student individual structuring of sensemaking as expressed in the concept maps. The results also showed a clear relationship between scientific language use and achievement level in the student sample. The results indicate that the structuring of sensemaking and scientific language use are not always connected processes. In conclusion, teachers may need to adopt a teaching practice that includes directed and differentiated support for scientific sensemaking.

Keywords Science education · Sensemaking · Language use · Student achievement · Concept maps

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Introduction

Sensemaking in science learning has been defined as "a dynamic process of building an explanation in order to resolve a gap or inconsistency in knowledge …built in one's own words, through an iterative process of construction and critique" (Odden & Russ, 2019, p. 199), while at the same time connecting to prior knowledge and lived experience. It has been shown that school students that are regularly engaged in scientific sensemaking learn the scientific content better than students who do not (Cannady et al., 2019). There has over the last decades been a growing interest in the relationship between language and sensemaking in science learning, from various perspectives, such as the role of language in comprehension and participation in learning (Cooper et al., 2022; Fang, 2016; Lemke, 1990, 2004), sensemaking as an essential aspect of scientific literacy (Adúriz-Bravo & Revel Chion, 2017; Norris & Phillips, 2003; Xu, 2022), the role that student conceptions play in the process of sensemaking (Jakobsson et al., 2009; Taber, 2017), the role of context in sensemaking (Ding et al., 2021; Vilhunen et al., 2023), and the interaction between language use and sensemaking in science classroom practices (Deng et al., 2022; Lee et al., 2013, 2018). This interest has been paralleled by changes in policy, for instance in the USA, where the Next Generation Science Standards include a significant shift towards sensemaking in science classrooms (Lee et al., 2018). Hence, there is a general consensus on the need for both the development of students' scientific language and sensemaking in science learning. This article presents a study exploring the relationship between student achievement level, scientific language use, and scientific sensemaking in a qualitative study of student language use in concept maps at upper-secondary school.

It is well established that learning the language of science is an essential aspect of science learning (Cooper et al., 2022; Fang, 2006, 2016; Lee et al., 2013, 2018; Lemke, 1990). Mastering the language of science means learning its grammar and precise vocabulary (Fang, 2005, 2006), managing its multimodal demands which include mathematical expressions and graphs (Hand & Choi, 2010; Lemke, 1998), and also its contextualized practices (Gee, 2004; Markic & Childs, 2016; Seah & Silver, 2020; Seah et al., 2014). Integrating science language learning as part of teaching practices can bring significant improvement in student achievement (Fazio & Gallagher, 2019). However, there are many challenges facing learners of the language of science, including learning the meaning of scientific terms (Vladušić et al., 2016) as well as symbols (Liu & Taber, 2016), and learning in which context certain scientific words and symbols are appropriate to use (Rector et al., 2013; Seah & Silver, 2020). Teachers are also in need of specific and explicit support in order to develop their classroom practices (Seah, 2016).

Sensemaking is essentially a language practice that involves the students' own words, both scientific and everyday ones (Kapon, 2017; Odden & Russ, 2019). Drawing from research in chemistry education, sensemaking can be described as involving an interaction of three knowledge domains through the use of language: describing phenomena, utilizing symbolic representations, and relating to relevant scientific models (Taber, 2013). This framework for understanding chemistry knowledge is in chemistry education referred to as the chemistry *triplet* (Johnstone, 2006; Taber, 2013; Talanquer, 2011). The triplet refers to the different domains of knowledge that students need to learn to connect and traverse between in order to learn chemistry (Taber, 2013), although these domains are defined somewhat differently in the chemistry education research literature. Generally, the triplet is defined as variations on three of the following domains of knowledge: the macroscopic and/or the experiential domain, the symbolic domain, and the submicroscopic (or particulate) domain (Johnstone, 1991; Taber, 2013; Talanquer, 2011). When students learn to navigate and connect these three knowledge domains as part of an integrated understanding of science, this increases their conceptual understanding (Jaber & BouJaoude, 2012). This type of integrated thinking is an essential part of making sense of science (Johnstone, 1991; Kozma & Russell, 2005; Schwendimann, 2015; Xu, 2022), but may take a long time to develop for students (Yaman, 2020). To use language to traverse these scientific knowledge domains in a structured manner, students are required to know specific terminology, link terminology to scientific concepts, and use both language and concepts in an appropriate way (Seah & Silver, 2020). The use of scientific representations (including mathematical expressions) as linguistic resources also plays an important role: a varied use of representations can give different insights as part of the sensemaking process (Prain & Tytler, 2022; Yeo & Gilbert, 2022).

In addition to the general language difficulties students face when learning science, challenges with relating between knowledge domains have also been observed, especially connecting theory to observable phenomena (Gunstone & White, 1981; Hofstein & Kind, 2012; Kind et al., 2011). Seah et al. (2011) have shown that students may have a poor understanding of how to connect theory to phenomena in an appropriate way linguistically as part of a sensemaking act in science, and that this in itself produces variation in sensemaking. It has been suggested that teachers need to spend more time helping students connecting these two knowledge domains (Abrahams & Millar, 2008), and that representations can be especially effective in mediating this connection (Pham & Tytler, 2022; Taber, 2013). However, students may not be able to differentiate between these knowledge domains, leading to difficulties in communication between teachers and students (Stieff et al., 2013).

Another challenge for teachers who wish to promote sensemaking in their classrooms is including all students in the sensemaking practice, as there can be variability in conceptual knowledge for students, even at the same achievement level in the same classroom (Hinton & Nakhleh, 1999). Additional challenges face teachers who work with students of different language abilities; low-achieving students of diverse language backgrounds can struggle with understanding the language of science, which can go unnoticed in a large classroom (Kousa & Aksela, 2019). Peer talk has been shown to be effective, especially for low achievers, in supporting sensemaking as part of a classroom practice (Rivard, 2004).

Although there are many studies in science education that discuss different aspects of language use in sensemaking, little attention has been paid to investigating the relationship between differences in language use, sensemaking, and achievement level in science. In order to find ways of supporting science teachers, it is therefore important to understand how learners with different scientific language repertoires differ in their scientific sensemaking. Also, in order to understand how learners' differing achievement levels are related to both their scientific language repertoires and their sensemaking capacities, it is important to differentiate between student achievement levels when exploring the relationship between language use and sensemaking. The focus of the work presented in this article was to explore the interrelationship between student language use, scientific sensemaking, and achievement level in order to inform teaching practices in diverse classrooms. In this paper, students' words are regarded as tools that are recruited to mediate the structuring of sensemaking, i.e., the organization of thought as a socially learnt practice (Arievitch & Haenen, 2005; Mercer, 2013).

Analytical Framework

Framework for Analyzing Scientific Language Use

The present study utilized research in language support for English language learners (Lee et al., 2013, 2018, 2019; Quinn et al., 2011) to define scientific language development for science learners as language becoming more *explicit* and *precise* when engaging in classroom tasks and describing scientific phenomena in collaborative practices. *Explicitness* means that students use scientific words rather than deictic words such as "this" or "here" (Lee et al., 2019), and *precision* means that students learn to use appropriate scientific concepts in a nuanced manner when describing a phenomenon. This definition was then compared with research on concept map assessment (Besterfield-Sacre et al., 2004; de Ries et al., 2022; Lopez et al., 2011; Ruiz-Primo et al., 1997, 2001a, b; Yin et al., 2005), to make use of previous reliable methods for comparative assessment of language use in concept maps. Common elements of successful methods for comparing the quality of propositions (the words connecting the concepts in concept maps) (Lopez et al., 2011; Ruiz-Primo et al., 1997, 2001a, b; Yin et al., 2005) and whole concept maps (Besterfield-Sacre et al., 2004) in the literature were combined, and then redefined in terms of various degrees of explicitness and precision of describing a scientific phenomenon. This definition of language use at different levels was then used as a starting point for the comparative analysis of student scientific language use in the concept maps.

Framework for Analyzing the Structuring of Sensemaking

To analyze student sensemaking in the present study, definitions of sensemaking in science (Odden & Russ, 2019; Taber, 2013; Zhao & Schuchardt, 2021) were related to a heuristic based on the chemistry triplet developed and used to successfully help upper-secondary school students explicitly make sense of chemistry through the use of structured reasoning using the triplet knowledge domains (Thomas, 2017). This heuristic was adapted according to the definitions of sensemaking and utilized as a framework to define knowledge domains included in structured sensemaking in the student concept maps that were analyzed (see Fig. 1).

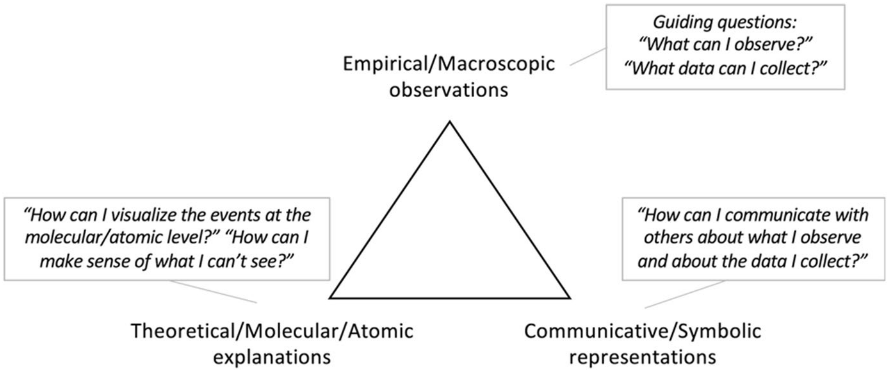

Fig. 1 Heuristic for structured sensemaking for upper-secondary school chemistry, with examples of guiding questions for students, adapted from Thomas (2017, p. 545). This modified heuristic for sensemaking, based on the triplet knowledge domains, was used as a starting point for comparative analysis of the structuring of sensemaking in the concept maps. Note that "symbolic representations" refers to for instance chemical equations or graphs

Study Aim

Using qualitative analysis, the objective of the present study was to explore the relationship between the explicitness and precision of upper-secondary students' scientific language and their structuring of observational, symbolic, and theoretical domains in sensemaking in concept maps in chemistry. In addition, previously assessed achievement level was explored as a possible factor related to both student language use and sensemaking. The research questions posed were:

- How does the explicitness and precision of students' scientific language relate to how they connect observable phenomena with symbols and theory as part of structured sensemaking, as exhibited through concept mapping in chemical equilibrium at upper-secondary school?
- How do students of different previously assessed achievement levels differ in terms of explicitness and precision of their scientific language use, and how do students of different previously assessed achievement levels differ in terms of how they connect observable phenomena with symbols and theory as part of structured sensemaking (as exhibited through concept mapping in chemical equilibrium at upper-secondary school)?

Research Rationale and Methods

Context of Study

The analysis of the data presented in this article consists of a sub-study within a larger research project focused on sensemaking in chemical equilibrium

Table 1 A summary of the contexts surrounding the students participating in the study

Class	School system (Lang.)	School type	School area	*N*	Year	Teacher description[a]
I	Swedish (Swedish)	Municipal	Inner city	18	2/3	Disengaged, but motivated during practical work
II	Swedish (Swedish)	Municipal	Small town	21	2/3	Mostly motivated, calm, and quiet
III	IB (English)	Municipal	University town	15	1/2	Motivated and hard-working
IV	Swedish (Swedish)	Private	Inner city	24	2/3	High-achieving and disciplined, very concerned about grades, poor in conceptual knowledge
V	IB (English)	Municipal	University town	10	1/2	Dedicated and engaged in the subject[b]

Lang., language; *N*, number of participating students; *IB*, International Baccalaureate

[a]Teacher's description of class during interview

[b]Data collected during COVID-19 pandemic, which meant the students' theoretical studies prior to data collection were conducted online

during practical lessons in five upper-secondary school classes in two school systems (Swedish and International Baccalauerate (IB)) in Sweden. The total data within this project consists of student-produced concept maps, student reflections and answers to questions about chemical equilibrium, student focus group recordings, films and observation protocols from classroom practical lessons, and teacher interview recordings. The topic of study, chemical equilibrium, was chosen because it is a topic that is hard for students to grasp (Driel & Gräber, 2002; Kind, 2004; Yan & Talanquer, 2015) and therefore was likely to produce a variation in student sensemaking suitable for comparative qualitative analysis (Cohen et al., 2018). Concept maps have previously been used to map connections between knowledge domains (Donner Junior et al., 2006; Schwendimann, 2011).

In total, 88 students ages 15–17 and five teachers volunteered to participate in the research project. The project utilized maximum variation sampling, which meant schools participating in the research project were chosen based on having differing student average achievement levels, location, school language, and organization (see Table 1). The students' most recently assessed achievement levels in the subject of chemistry were provided by the teachers. According to this data, overall, Class I was low-achieving, Class II had students of mixed achievement levels, Class III was high-achieving, Class IV was very high-achieving, and Class V was a mixed-achievement group containing fewer high-achieving students compared to Class II. In total, slightly less than half of the students represented the two highest achievement levels in chemistry, and the rest of the students were evenly distributed across mid-, low-, and failing levels. As can be seen in Table 2, both school systems include elements of sensemaking and language use in their grade descriptors.

Most students had not used concept mapping before, and about a third spoke a different language at home from the language spoken at school which was

Table 2 An overview of the student abilities that are graded in the subject of chemistry for the two school systems, summarized from each school system's grade descriptors (International Baccalaureate Organization, 2017; Skolverket, 2022). Elements that can be directly related to sensemaking and language use are displayed in bold text. Note that although the Swedish grade descriptors were recently updated in 2022, this update did not concern the abilities being assessed when the study took place

Swedish school system	International Baccalaureate Diploma Programme
Account for concepts, models, theories, and methods	Display chemistry knowledge and knowledge of concepts and principles
Use models to answer questions and reason about chemical events	Analyze and evaluate quantitative and qualitative data
Account for models, their development, and their affordances and limitations	**Explain phenomena and make predictions**
Analyze and find answers to theoretical and practical chemistry problems	Solve problems
Perform experiments and evaluate own abilities in collaboration with the teacher. **Interpret, and reason about, the results from experiments and observations**	**Use the language of science to communicate appropriately**
Discuss the importance of chemistry to individuals and societies	Pay attention to ethics, safety, and the environmental impact of investigations
Use the language of science to communicate appropriately and evaluate sources	**Design and perform practical work with appropriate analytical techniques, and make conclusions relevant to the problem posed**

representative of the national average (Skolverket, 2020). The teachers were all very experienced, with between 15 and 30 years of experience as teachers of chemistry.

To investigate student language use in relation to student sensemaking, the present study utilized content analysis (Spencer et al., 2014) to analyze the students' concept maps in terms of (a) student explicitness and precision of word use in describing chemical equilibrium, and (b) student structuring of sensemaking in terms of the structuring of and connecting between triplet knowledge domains in their concept maps. This analysis of the concept maps was then viewed in relation to reported student achievement levels (provided by teachers with student consent). All the concept maps analyzed were produced by the students before a practical lesson in chemical equilibrium focused on shift in position of chemical equilibrium (a chemical process commonly illustrated to students by color change in solutions). To understand the context within which the concept maps were produced, teacher interviews from the research project focusing on the teaching context of the practical lesson were also used to inform the analysis of the data. The timing of the concept mapping session ensured a certain degree of preparedness on behalf of the students in terms of theoretical knowledge on chemical equilibrium as they constructed the concept maps (this was also confirmed in the teacher interviews), and therefore preparedness in sensemaking about chemical equilibrium as an observable phenomenon. Data from teacher interviews and learning materials from the research project confirmed that all students had followed roughly the same teaching sequence prior to drawing the concept maps, which included an introduction to reversibility with a focus on particle collisions and kinetics, followed by a (sometimes brief) introduction to the Equilibrium Law. In some cases, the students had also worked with Le Chatelier's principle.

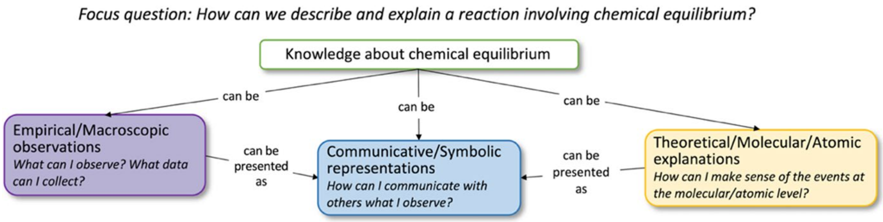

Fig. 2 Scaffold used by students during the concept-mapping session on shift in chemical equilibrium, adapted from the sensemaking heuristic of Thomas (2017). This scaffold modelled the structuring of, and connection between, observations, symbolic representations, and explanations. The scaffold also restricted the concept-mapping topic through the use of a focus question

Data Generation and Analysis

Procedure

For the research project, students were taught concept mapping by the researcher in the school language during an 80-min class adapted from the method by Ruiz-Primo et al. (2001a, 2001b). The method involved a presentation explaining what concept maps are and how they are constructed, a collective concept map construction exercise including student feedback, introduction to the triplet knowledge domains with examples (using a sensemaking heuristic adapted from Thomas, 2017), and finally the construction of practice concept maps (on the topic of thermodynamics) in pairs assisted by the researcher (during the COVID-19 pandemic, for class V, this assistance was provided by the regular teacher). These concept maps were assessed to check that all students constructed concept maps according to an announced topic-restricting focus question (Cañas et al., 2012; see Fig. 2), which they did. After this, students were given 20–25 min to construct the concept maps on the topic of shift in position of equilibrium that were later used for the analysis.

For both the construction of the practice concept map and the concept map on the topic of shift in position of equilibrium, the students were given the following: a step-by-step instruction handout; a starting scaffold for the concept maps encouraging sensemaking about observations, symbolic representations and theory (based on the sensemaking heuristic; see Fig. 2); and five starting concepts central to the concept-mapping topic defined by the focus question. A general example map with examples of types of concepts that could be interpreted as having observational/empirical, symbolic, or theoretical uses in sensemaking was also handed out. In addition to the starting concepts, the students were asked to add concepts of their own. The students were asked to first sort the concepts according to the concept map scaffold, and then connect them into statements that related the theory to a proposed observation (e.g. color change). The sorting of the concepts generally took 10–15 min for all groups. Encouraging the iterative process of sensemaking, the students were also instructed to revise their statements until satisfied and use all the concepts given (including "color change," an experiential concept unknown to the students in the context of chemical equilibrium).

An evaluation of how well the students followed the instructions for concept mapping showed that 91% of the participants used all the concepts provided, 99% used labelled lines, and 99% provided one or more valid propositions, with no significant difference between the different student groups (classes I–V). This result was in line with previous uses of this teaching method (Ruiz-Primo et al., 2001a, b), and it was concluded that the students had learnt how to construct concept maps in all the classes. Poor training in concept mapping can be shown through a divergence between how students express their understandings verbally and what is written in their concept maps (Jin & Yoong Wong, 2010). Therefore, all of the teachers were asked to verify the representativeness of the student reasoning about chemical equilibrium in three concept maps from their respective classes, and all of these maps were judged to be representative of the student's knowledge of chemical equilibrium. These three concept maps were randomly picked to represent one low-achieving student, one medium-achieving student, and one high-achieving student from each class.

Concept Map Design Rationale

For the research project, the design of the concept maps followed the recommended concept-mapping procedure for students of this level; that is, a focus question, a beginning scaffold, and a small list of starting concepts (Cañas et al., 2012). A selected set of starting concepts for the concept maps ensured that a valid comparison of the maps could be made (low-achieving students have been previously observed to choose less relevant concepts for their maps (Ruiz-Primo et al., 1997)). At the same time, allowing own concepts ensured that students had some freedom of expression in terms of the topic of the map (Cañas et al., 2012). The placement of the symbolic domain in the middle of the concept map scaffold was based on research (Yaman, 2020) showing that symbols are used to link theoretical and experiential domains in chemistry.

The five beginning concepts chosen for the students' maps were the following: "color change"; "reversible"; "$\rightleftarrows$" or "$\rightleftharpoons$" for the Swedish and the IB curriculum, respectively; "K" or "K_c" for the Swedish and the IB curriculum, respectively; and, finally, "concentration." The choice of the concepts was based on the following criteria: (a) they were necessary concepts for the practical work on shift in position of equilibrium that all of the students were about to undertake; (b) all knowledge domains involved in the structuring of sensemaking were represented (that is, observational/experiential, symbolic/representational and theoretical/explanatory); and (c) the concepts were present in both the content of the IB Diploma Programme syllabus (International Baccalaureate Organization, 2014) and the content of the Oxford IB Chemistry Course Companion (developed with the IB; Murphy et al., 2014), as well as the content of three major chemistry course books for Swedish upper-secondary school (Borén et al., 2012; Sonesson et al., 2013; Henriksson, 2012).

Analysis

For the present study, the explicitness and precision of language and the structuring of and connection between triplet knowledge domains in the student-produced concept maps were subjected to content analysis, where framework analysis (Ritchie et al., 2014) and a constant comparison approach were utilized for data organization and coding consistency. The framework analysis meant that coding was done in NVivo and in a separate coding matrix, where relevant statements from the concept maps were charted into a matrix with coding labels. Constant comparison meant the codes were checked repeatedly for consistency throughout and code definitions were kept in a codebook. Both overarching themes for coding, i.e., student language use and student structuring of sensemaking, used the analytical framework for categorization in a theoretical first wave of coding. For example, scientific language use was initially grouped according to the four levels (0–3) most commonly found in the research literature. In a second wave of coding, the codes were then refined inductively. The final categories did not change as data from the last two student groups was added, indicating data saturation (Cohen et al., 2018, p. 601). Code definitions were maintained and updated in a codebook (for an example of final code definitions, see Table 3; see also Hamnell-Pamment, in press). Coding was accompanied by regular memoing (Cohen et al., 2018, p. 719). When finalized, the codes of twenty randomly picked concept maps were evaluated externally by an associate professor of educational sciences with a PhD in Science. The coding of three of these concept maps was divergent, whereby the codes were discussed until a consensus was found. The coding of the remaining concept maps was then checked and corrected according to consensus where needed. All concept maps were coded in their original language and only translated for the purpose of publication. The translation of the concept maps was checked externally by both a director of studies/researcher and a professor from the Department of Chemistry at Lund University, the latter of whom teaches chemical equilibrium to undergraduates. Following this, a few minor changes were made to the translations for clarity. As a note, all students incorporated the "concentration" concept correctly into their maps, confirming they all could connect to previous knowledge during sensemaking in the study.

For the analysis of how the coding related to previous individual student achievement, the students' previously assessed achievement levels in chemistry (A to F in the Swedish system and 7 to 1 in the IB system) were grouped into similar levels of achievement (an A corresponding to a 7, etc.[1]) according to recommendations by the Swedish Council for Higher Education (2020). Sixteen students did not wish for their grades to be connected with their work or their personal information, and were therefore excluded from this analysis.

[1] In the Swedish grading system, the highest grade A can be said to correspond to extensive and nuanced reasoning, a C to extensive reasoning, an E to synoptic but satisfactory reasoning and an F to not fulfilling the requirements for E; the grade B fulfils the requirements for grade C but also to a large extent grade A and the grade D works equivalently as a grade in-between E and C (Skolverket, 2022). The IB student grades range from 1 = fragmentary to 7 = comprehensive knowledge (International Baccalaureate Organization, 2017).

Table 3 Final codebook definitions for the theme student language use in the student-produced concept maps. Adapted from Hamnell-Pamment (in press). Note that the "connections" between the concepts in this table refer only to the connecting words between the concepts, and do not refer to the organization of the connections between the triplet knowledge domains

Initial category	Further defined category	Student language use in terms of explicitness and precision[a]
3	3	Chemical equilibrium is defined in a clear and precise language in these maps, connecting the essential concepts. Most aspects of chemical equilibrium at this level are covered, and concepts are defined when relevant
2	2+	Several relevant concepts are connected through a coherent definition of the equilibrium process. The concept maps may contain some vague parts but also relevant concept definitions
	2-	Some relevant concepts are used to provide a clear but partial definition of chemical equilibrium in these maps. Occasionally, one of the propositions in a concept map may be incorrect but at least the language is explicit. Some concepts may be connected through vague language
1	1+	Some concepts related to chemical equilibrium are described superficially in these maps. The concept maps are somewhat coherent in how the concepts are connected. Occasionally, concept definitions are given
	1-	One or a few concepts related to chemical equilibrium are brought up in these maps, mostly in a vague manner. Less relevant concepts are also sometimes used, and the concepts can be connected through somewhat incoherent language
0	0	Non-existent or insufficient connecting words between concepts are given in these concept maps. Vague language is used. The concept maps can have irrelevant sections and/or incorrect/insufficient expressions

[a]Description of language use and definition of chemical equilibrium in the concept maps that belong to the category

The NVivo query function was utilized to explore the relationships between the different coding themes emerging from the data. The trends that were found were then confirmed using exploratory Spearman's rank-order correlations calculated in SPSS between the dimensions (i.e. categories) of the finalized coding themes of *student language use* and *structuring of sensemaking*, as well as between these two coding themes and the individual student achievement levels. In order to calculate the correlations, the categories within both of these two coding themes were changed into Likert scales and ranked alongside the achievement levels. Differences in category frequency at group level (i.e. between classes I and V) were also visualized in graphs.

Compliance With Ethical Standards

As no sensitive data was collected during the study and the participants were not at risk of any injury from participating, no ethical permit was required for the study according to Swedish law (SFS 2003:460). Instead, the study followed the general ethical guidelines issued by the Swedish research council (2011). In brief, participation was voluntary, participants could quit at any time, and the participants were fully informed of the study, its purpose, and how the data would be handled. Informed consent forms were signed by the participants; no parental permission was required according to Swedish law since the students were over 14 years of age (SFS 2003:460 18§). Data was handled in accordance with the EU General Data Protection Regulation.

Considerations Regarding the Methodology

As this was a qualitative study, the findings have low generalizability (Cohen et al., 2018). However, qualitative studies can on the other hand explore context and nuances in data that statistical analysis cannot (Flyvbjerg, 2001). This perspective would seem especially relevant when comparing textual quality.

If students are trained correctly to use them (Jin & Yoong Wong, 2010), concept maps can be useful tools for formative assessment. The validity of their use to assess propositional quality, i.e., the explicitness and precision of statements, using common scoring rubrics (such as the ones used for the analytical framework of this paper) has been thoroughly established (Besterfield-Sacre et al., 2004; Ruiz-Primo et al., 2001a, b; Ruiz-Primo et al., 2001a, b; Stoddart et al., 2000). Their utility to assess connectedness or disconnect between concepts and knowledge domains as part of knowledge integration has also been established (de Ries et al., 2022; Kinchin, 2020; Novak, 2002; Schwendimann & Linn, 2016). Hence, concept maps produced as part of a classroom sensemaking exercise were deemed appropriate to use as tools to assess student scientific language use and structuring of sensemaking.

From a sensemaking perspective (Thomas, 2017), the concept of *reversible*, together with the Equilibrium Law, is used to from a scientific perspective explain the changes in color observed during practical lessons on chemical equilibrium at upper-secondary schools in Sweden. To make this definition of sensemaking clear to the students, the wording of the adapted sensemaking heuristic contains the words "observations," "representations," and "explanations" for the three triplet knowledge domains. The primary purpose of the heuristic used in the study is to promotive reflection, and the language of the heuristic is expected to be adapted to fit the needs of the situation (Thomas, 2017). Hence, what is shown in the concept maps in the present study is students' *perceptions* of which concepts and connecting words are suitable to use when making sense of phenomena related to chemical equilibrium (i.e. language use), and how they *organize and connect* these concepts in terms of how they are used (i.e. structuring of sensemaking).

Results

Relationship Between Student Scientific Language Use and the Structuring of Sensemaking About Shift in Position of Equilibrium

Through coding, the maps were divided into four types in relation to their sensemaking structure. Notably, only 14 out of 88 students established structured sections of observations, symbolic representations, and explanations fully in their maps, even though all students spent a long time placing concepts during the exercise. Typical for maps with structured sections were a clearer language (i.e. more explicit and precise) compared to other concept map types (see overview of language use distributions in Fig. 3a), and connectedness between concepts as well as triplet knowledge domains (see Fig. 3b).

Figure 4 shows an example concept map of the second type. In these maps, students connected concepts of an appropriate type (observational, symbolic, or explanatory) to the scaffold, but then did not structure the rest of the concept map according to the indicated triplet knowledge domains; instead, part of the map was of mixed structure. These concept maps were presented as linear or branched, parallel or partially parallel narratives using the three triplet knowledge domains indicated by the scaffold as a starting point. Hence, there were either few or no connections between the triplet knowledge domains of these maps. The concept maps of this type had a more even distribution of categories of language use compared to Type 1 maps (see Fig. 3a).

Figure 5 shows an example of the third type of concept map. In these concept maps, students structured the concept maps somewhat in terms of the triplet knowledge domains, but used symbolic representations as part of observations and/or explanations. These concept maps were also presented as linear or branched, parallel, or partially parallel narratives using the scaffold as a starting point. These maps all showed unstructured sensemaking in a mixture of statements about chemical equilibrium that lacked overall coherence. These concept maps were less explicit and precise in terms of scientific language use compared to the first two types (see Fig. 3a).

Figure 6 shows an example of the fourth type of concept map. This type had no established sections of observations, symbolic representations, and explanations, thereby showing unstructured sensemaking in terms of organization of, and

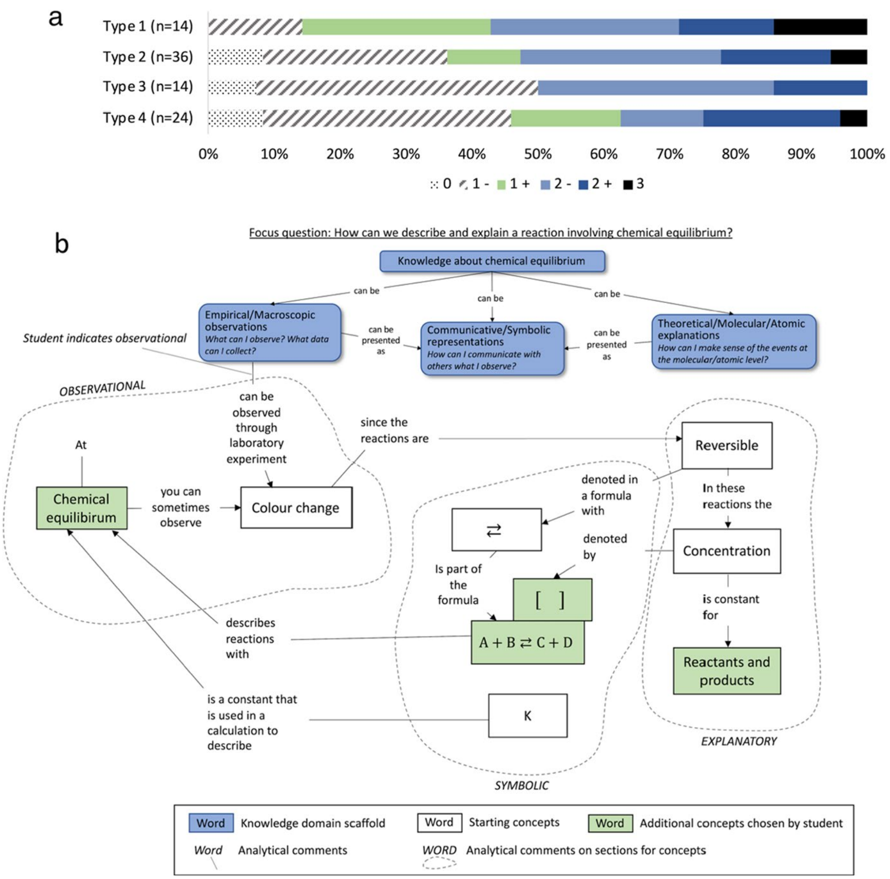

Fig. 3 **a** An overview of language use distributions (explicitness and precision ranging from 0 = incorrect/irrelevant/not mediating sensemaking about chemical equilibrium, to 3 = complete and correct in terms of explicitness and precision in relation to what has been taught) for concept map types 1 through 4. **b** A student-produced concept map of type 1 (computerized), with structured knowledge domains for observations, symbolic representations, and explanations, including analytical comments. This concept map belonged to language use category 2 –

connection between, triplet knowledge domains. These concept maps either showed nonsensical connections to the scaffold, or a completely separate narrative that did not relate to the scaffold. A large proportion of these unstructured maps was written in vague language, but there was also a proportion of type 4 maps with more explicit and precise language (see Fig. 3a). The unstructured maps were of varied shapes: linear, interconnected, or branched from a central concept. In common, however, was a distribution of concepts that was associative rather than structured, i.e., focused on producing several statements rather than a structure. Notably, out of the nine students that used more explicit and precise language (scores 2–/2 + /3) but made no attempt to structure regions of observations, symbolic representations, and explanations in their maps, eight were from the very high-achieving class (class IV)

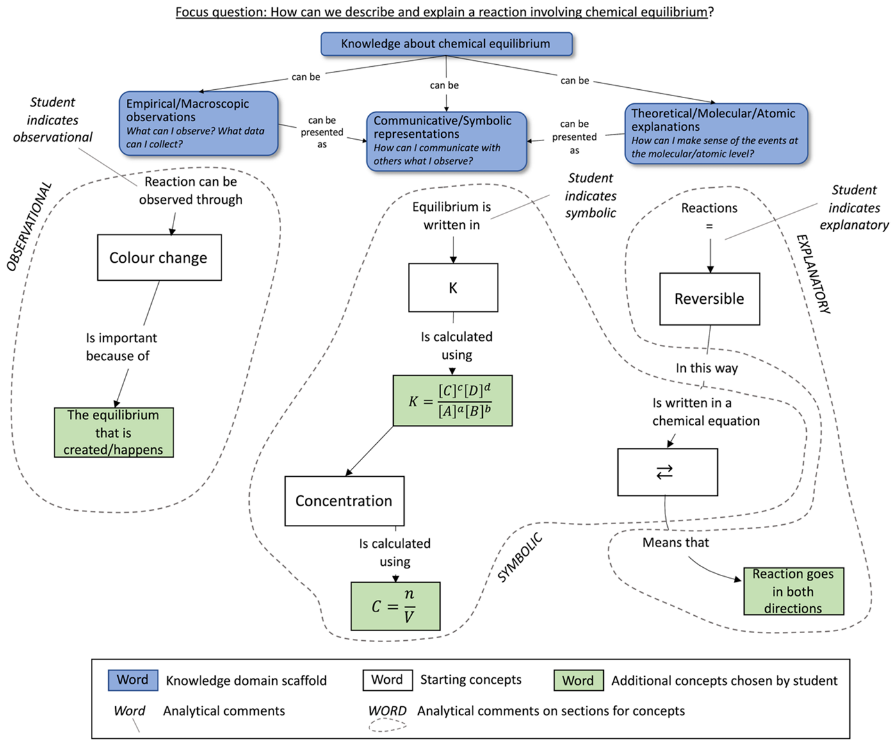

Fig. 4 A student-produced concept map of type 2, with established sections for observations, symbolic representations, and explanations, but with an aspect of a mixed structure in terms of the triplet knowledge domains (symbolic representation as part of the explanation), including analytical comments. This concept map belonged to language use category 2 –

that according to the teacher was poor in conceptual knowledge (teacher 4, interview 1, September 17, 2019; see Table 1).

No correlation was found between the explicitness and precision of student language use and the different degrees of structuring and connecting the triplet knowledge domains as part of sensemaking ($r_s = 0.14$; $p = 0.19$). In conclusion, highly structured concept maps in terms of sensemaking in the data sample more often had more explicit and precise language compared to less structured maps, but the sample also contained high variability.

Relationship Between Student Scientific Language Use and Previously Assessed Achievement Level

In statistical explorations of data, precision and explicitness in student scientific language were found to have a high (considering the complexity of the measured variables; Schober & Schwarte, 2018) correlation with achievement level as measured by Spearman's rank-order correlation ($r_s = 0.67$; $p < 0.001$). A general trend was seen

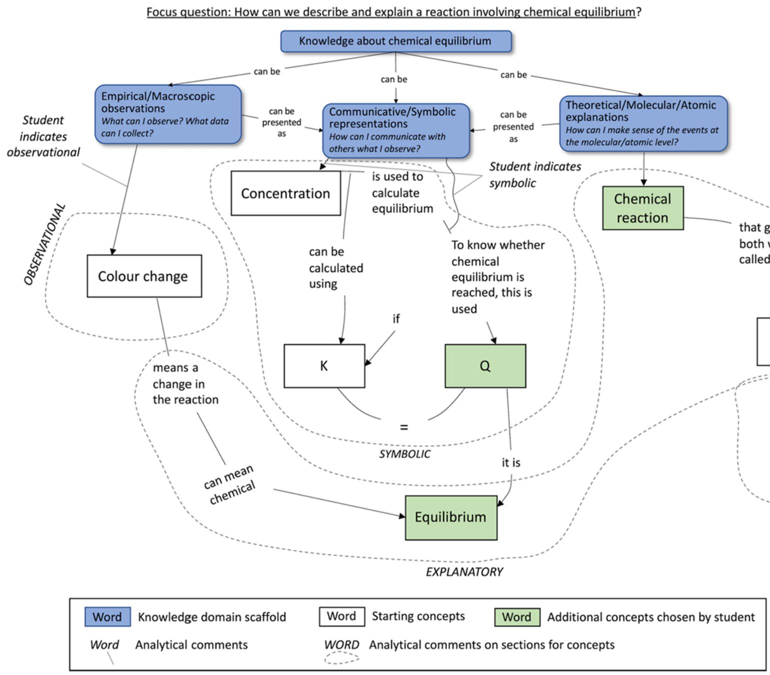

Fig. 5 A student-produced concept map of type 3, with blended sections for symbolic representations versus explanations (i.e. symbolic vs. explanatory knowledge domains), including analytical comments. This concept map belonged to language use category 1+

in terms of explicitness and precision of scientific language increasing with higher assessed achievement level (see Fig. 7). An illustration of these language differences is shown in Fig. 8. This increase in use of appropriate terminology and less use of vague language included choice of concepts (from less to more relevant) and use of words connecting the concepts (from vague to more elaborate and clearer) in the concept maps. Hence, although some variability was observed in terms of language within each previously assessed achievement level (see Fig. 7), the higher-achieving students were generally more adept at using their scientific language for the purpose of describing chemical equilibrium.

Relationship Between Student Previously Assessed Achievement Level and the Structuring of Sensemaking About Shift in Position of Equilibrium

In statistical explorations of data, no correlation could be found between degree of structuring of sensemaking (indicated by degrees of connecting and organizing triplet knowledge domains in map types 1 through 4) and previously assessed student achievement levels in chemistry ($r_s = -0.57$; $p = 0.636$). A comparison of the relative proportions of the map types 1 through 4 in the different student classes showed a difference in category frequency between the students' concept map sensemaking

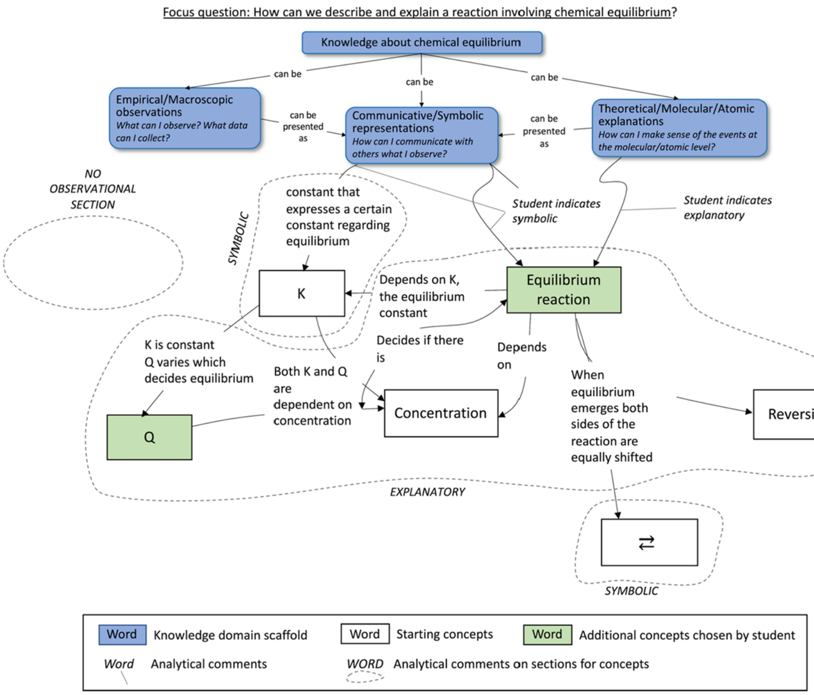

Fig. 6 A student-produced concept map of type 4, unstructured in terms of triplet knowledge domains, including analytical comments. This concept map belonged to language use category 1+

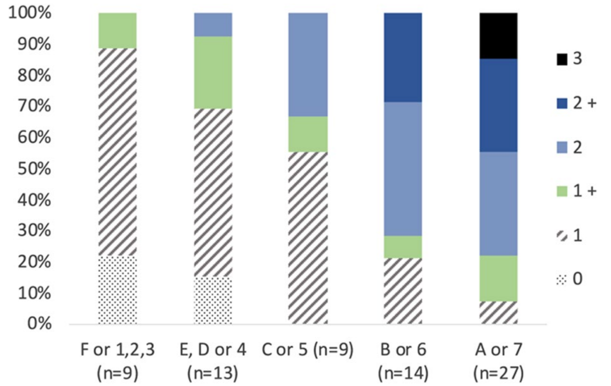

Fig. 7 The explicitness and precision of scientific language use in the concept maps, divided into categories 0 (incorrect, irrelevant or not contributing to sensemaking about chemical equilibrium) to 3 (complete and correct in terms of explicitness and precision in relation to what has been taught), with percentage of different maps scores shown for students grouped by previously assessed achievement levels in chemistry, increasing from left to right. An F or 1, 2, and 3 represent failing levels in the Swedish or International Baccalaureate school system, respectively

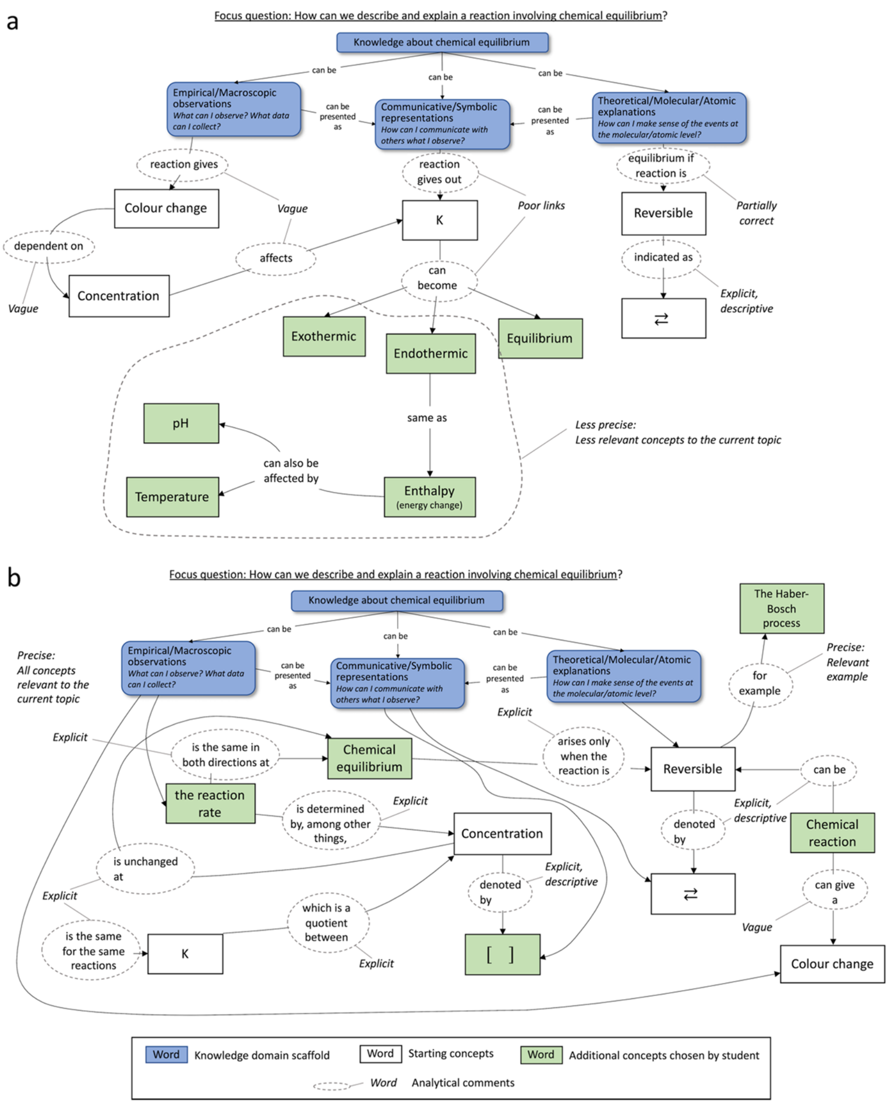

Fig. 8 An illustration of the differences in explicitness and precision of scientific language expressed by the students in the sample, including analytical comments. **a** Concept map produced by a student with previously assessed achievement level E in chemistry and map score 1–. **b** Concept map produced by a student with previously assessed achievement level A in chemistry and map score 2+

structure depending on which class they were part of (see Fig. 9a). For instance, students in class I, which were low-achieving (see Fig. 9b), produced a large proportion of type 4 concept maps, whereas students in class IV, which were very high-achieving (see Fig. 9b), also produced a large proportion of type 4 concept maps. On the other hand, concept maps from class III were mostly type 1 or 2, and this class was described as "motivated and hard-working" by the teacher (see Table 1). The

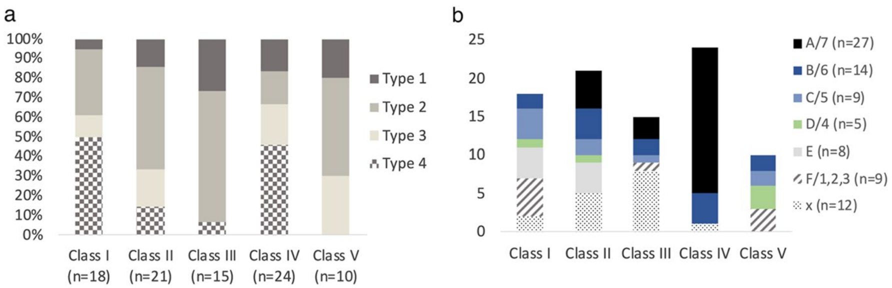

Fig. 9 **a** The distribution of structuring of sensemaking represented by the structuring of, and connecting between, triplet knowledge domains, i.e., observations, symbolic representations, and explanations, expressed in the student concept maps. The percentage of different types of structuring of sensemaking is shown for the different student classes. Types of structuring of sensemaking: Type 1—triplet knowledge domains organized and connected; Type 2—triplet knowledge domains partially organized and less connected; Type 3—blends of symbolic representations versus explanations; Type 4—triplet knowledge domains not organized. **b** The achievement level distribution for each class. An F or 1, 2, and 3 represent failing levels in the Swedish or International Baccalaureate school system, respectively; *x* represents students not consenting to share their previously assessed achievement levels. Classes I, II, and IV were from the Swedish school system and classes III and V were from the International Baccalaureate school system

high level of type 4 maps in the very high-achieving class (class IV, where most had the highest possible chemistry grade) can be viewed in relation to the interview data, where teacher 4 described the group as poor in conceptual knowledge and worried about grades (teacher 4, interview 1, September 17, 2019; see Table 1).

Discussion

The aim of this study was to investigate how the explicitness and precision of upper-secondary students' language use and achievement level is related to how they structure and connect observations, symbolic representations, and explanations during sensemaking about chemical equilibrium in a data sample containing student-produced concept maps from five school classes in Sweden. One important finding was that only 14 out of the 88 students produced concept maps with fully structured sensemaking in terms of observations, symbolic representations, and explanations in relation to a phenomenon. Many of the other students' concept maps showed disconnected sensemaking between the triplet knowledge domains. The triplet knowledge domains in these concept maps either had linear shapes, indicative of rote learning (Kinchin, 2020; Novak, 2002), or branched shapes, indicative of superficial or unreflective learning (Kinchin, 2020). Rote learning and disconnect between core concepts have also been observed in concept maps produced by prospective chemistry teachers (Kibar et al., 2013); hence, this is not a surprising finding.

The degree of structured sensemaking in terms of structuring and connecting the triplet knowledge domains in the concept maps overall varied between the different student groups, and was not related to previously assessed achievement level. Possibly, individual sensemaking could be context-dependent, as indicated by the differences between the student classes in terms of structuring of sensemaking shown through differences in frequency distribution of concept map types. A plausible instance of context-dependence could for instance be seen in the case of the high-achieving student class that according to their teacher struggled conceptually and according to their concept map shapes in many cases learnt chemistry superficially and did not structure their sensemaking in a meaningful way. This connection between rote learning and lack of sensemaking is consistent with research on student approaches to learning showing that students that adopt a surface approach tend to focus on memorization, and do not engage in the sensemaking learning practices typical of deep learning approaches (Biggs et al., 2001; Marton & Säljö, 2005; Schneider & Preckel, 2017). Differences in the structuring of sensemaking depending on both class achievement level and learning context could also be explained by the strong links shown in the research literature between social dialogue and students' individual reasoning and reflection (Mercer, 2013), both important components in sensemaking (Odden & Russ, 2019). Framing of the classroom dialogue has previously been shown to influence sensemaking (Ding et al., 2021). Hence, the influence of context on student structuring of sensemaking is an interesting topic for further research.

Although there was generally more precise and explicit language in the highly structured type 1 maps and generally vaguer language in the more unstructured maps of types 2–4, it would seem that in some cases, student language could be explicit and precise and at the same time lack an overall structure in terms of sensemaking in the concept maps. The data showed no clear relationship between individual structuring of sensemaking in terms of structuring and connecting the triplet knowledge domains and previously assessed achievement level, especially for the group of students with unstructured concept maps and high achievement levels. This suggests that some students in the data sample were highly communicative in scientific language and thereby achieved well, but still struggled to make sense of chemistry phenomena. As rote learning impedes knowledge integration (Novak, 2002), and a well-differentiated knowledge framework indicates deep learning strategies (Pearsall et al., 1997), it might be suggested that these students had learnt to speak the language of chemistry by rote or surface learning, and thereby not learnt to organize their sensemaking as a conscious and integrated reasoning practice. This result is similar to previous research showing how results-focused students can use a surface approach to learning that enables them to effectively connect concepts without showing understanding (Marton & Säljö, 2005; Säljö, 1975). A surface-approach to learning can also be the result of anxiety due to pressure to perform (Cipra & Müller-Hilke, 2019; Postareff et al., 2017), and concern for grades was indeed noted by the teacher to the group containing students exhibiting highly explicit and precise language in combination with unstructured concept maps. A disconnect between student verbalization and sensemaking in science has also been observed previously by individual teachers (Kousa & Aksela, 2019). The connection between student communicative ability and achievement level is confirmed by the fact that high-achieving students in the study generally used more explicit and precise language compared to low-achieving students. Indeed, students' general and scientific vocabulary contributes significantly to their ability to answer test questions correctly

(Taboada, 2012). Interestingly, surface approaches to learning that include strategic choices that maximize exam results have been correlated with achievement in science at some upper-secondary schools (Ardura & Galán, 2019); however, memorization and rote learning do not lead to long-term success, as shown by the negative correlation between surface approaches to learning and achievement at university level (Schneider & Preckel, 2017; Sinapuelas & Stacy, 2015).

In conclusion, it would seem that how well students use the scientific language and how well they structure their sensemaking in chemistry are not directly connected processes. The results suggest that structured sensemaking in chemistry defined as structuring of and connecting between triplet knowledge domains may need more support at some upper-secondary schools in Sweden. In view of common university textbooks in general chemistry only allocating 1% of end-of-chapter problems to connecting between observations, symbolic representations, and particulate explanations (Dávila & Talanquer, 2010), this could likely be an issue for science learners in other countries as well. This suggestion is corroborated by the study of Yaman (2020), who showed that connecting observations, theory, and symbolic representations to form high-quality arguments in making sense of phenomena is a practice that takes time to develop even at university level. Teacher support in structuring sensemaking could be especially important as part of a differentiated teaching practice supporting deep learning approaches for all students.

The main implications from the present study are for teachers and researchers to problematize how they design sensemaking activities for differentiated instruction. Students of different achievement levels may need different types of support in developing both their scientific language and their sensemaking practice. From a second-language–learner perspective, social practices need to be explicitly taught alongside the words of the language (Mohan, 2001), and this has also been suggested for teaching scientific language use (Nygård Larsson & Jakobsson, 2020). Research suggests social supports are particularly important for individual learning (Mercer, 2013), where low-achievers tend to benefit the most (Rivard, 2004). Extrapolating from the results of this study, such an approach may involve supporting low-achieving students in choosing the most appropriate concepts for reasoning about phenomena, and engaging all students in peer discussions on sensemaking with explicit teacher guidance. Introducing such supports could potentially buttress both deep-learning approaches and student achievement. Such practices would be in line with preparing upper-secondary students for the demands of university learning.

As already mentioned, the results from the study are not generalizable to larger student populations. However, the disconnect found in the study between student structuring of sensemaking and previously assessed student achievement levels indicates that current assessment forms, such as tests, may not be adequate for assessment of sensemaking. Instead, alternative assessment forms, such as teacher-student dialogues based on structural types of student-produced concept maps (Kinchin, 2020), may be needed to complement changes in government policies such as the Next Generation Science Standards. In short, the data from this study suggests that, in order to support students making sense of phenomena, teachers need to adopt a practice that involves both differentiated language support and structuring support for sensemaking, as well as appropriate assessment practices.

Acknowledgements This study is part of a collaboration between the Department of Chemistry and the Department of Educational Sciences at Lund University. The article is a product of the joint effort of author writing and seminar discussions. Thank you to Dr. Susanne Pelger for taking the time to evaluate the coding procedure.

Funding Open access funding provided by Lund University.

Data Availability The datasets generated and analyzed during the current sub-study are not publicly available due the fact that they constitute a part of research in progress. However, they are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The author declares no competing interests.

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