Science & Education (2023) 32:481–498
https://doi.org/10.1007/s11191-021-00316-w

ARTICLE

Exploratory Considerations in Chemistry Education—Didactic Modelling for Complexity in Students' Discussions

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Accepted: 7 December 2021 / Published online: 3 January 2022

Abstract

Research has shown the importance of dealing with real-life issues and of enabling student encounters with complexity in chemistry education in order to increase student participation. Therefore, this study aims to analyse how complexity evolves in students' discussions and how this complexity relates to aspects of tentativeness in chemistry. In the study, we analyse how a previously developed didactic model can be refined from the students' considerations evolving from the present context. The study was conducted as an in situ study in one upper-secondary school. Students' discussions were recorded on video. The recordings were transcribed and analysed using deliberative educational questions. Two different kinds of considerations emerged in the students' discussions: *factual and exploratory considerations.* While factual considerations are an important element of chemistry education, students also need to encounter exploratory considerations. The study proposes a didactic model useful for teachers in didactic analysis and design of activities aiming to support students to unfold complexity through exploratory considerations. One implication is to base activities on real-life issues in order to invite the unpredictability needed for experiencing complexity and the exploratory nature of chemistry. These issues enable students to experience aspects of tentativeness in chemistry and thereby increase their understanding of NOS and chemistry as a knowledge building practice. Furthermore, this might also increase student participation in chemistry education.

Keywords Chemistry education · Upper-secondary education · Didactic modelling · Complexity · Scientific Literacy

1 Introduction

Science education needs to address real-life issues and complexity to prepare young people for life's challenges. Accordingly, education should include activities where students can encounter real-life issues and experience complexity. Furthermore, science education also

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needs to inculcate in students a willingness to engage with scientific issues and take part in scientific practices. According to research, one fruitful way to increase student participation in science education might be to allow them to experience the aspects of tentativeness in science. Therefore, this study aims to explore how complexity is construed by the students and how this complexity is to be found in the exploratory nature of chemistry in their discussions.

2 Background

2.1 Science Education for Citizenship

Science education for citizenship is a broad concept; its general aim is to prepare students for present and future challenges. One aspect is to support students' development of scientific literacy (SL). However, there is no consensus on the definition of scientific literacy; the concept is usually used to 'express what should constitute the science education of all students …' (Roberts, 2007, p. 729). Roberts (2007) describes two different curriculum perspectives on scientific literacy, Vision I and Vision II: 'Vision I gives meaning to SL by looking inward at the canon of orthodox natural science, that is, the products and processes of science itself (Roberts, 2007, p. 730). On the other hand, 'Vision II derives its meaning from the character of situations with a scientific component, situations that students are likely to encounter as citizens' (Roberts, 2007, p. 730). Vision II includes real-life issues and thereby aspects of uncertainty and risk, thus presenting a less uniform and often more student-centred approach to science education (Roberts, 2007). Vision II is related to a *Bildung*-oriented science education (Sjöström et al., 2017; Wickman, 2014). *Bildung* includes personal and societal development and solidarity and responsibility for acting towards positive changes in society (Elmose & Roth, 2005). This is also in line with Brickhouse and Kittleson (2006), who request a science education which enables students to develop a willingness to participate in scientific practices aimed at developing an ecologically and socially just society.

2.2 Relevance and Authenticity in Chemistry Education

A review of the use of relevance in science education states that the concept is not clearly defined (Stuckey et al., 2013). Relevance is often regarded as a synonym for students' interest or as their personal perception of meaningfulness (Stuckey et al., 2013). Most studies regarding students' opinions about the relevance of chemistry education indicate that students find it difficult to connect science content knowledge to their everyday life. Furthermore, the scientific content and pedagogical methods it is presented by are seldom perceived by the students to be relevant (e.g. Aikenhead, 2006; Hofstein et al., 2011).

Others argue that science is often presented in a way that gives the impression of a subject which is hard to learn, devoid of connections to everyday life and where there is no room for creativity, emotions and morals (e.g. Brickhouse, 2011). This contributes to the students' image of science as uniform and absolute (e.g. Kelly, 2014; Lemke, 1990). However, these studies are conducted through interviews or questionnaires, requesting students' opinions regarding chemistry education, aiming to identify challenges and problems within science education. Therefore, it seems more research regarding how to address these challenges is needed and more in situ studies required to develop tools for teachers to use in their efforts to challenge the prevailing teaching traditions. In later years, EU-funded projects such as PROFILES (Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science), PARRISE (Promoting Attainment of Responsible Research and Innovation in Science Education) and others have tried to tackle students' low interest in science, developing teaching modules for science education in collaboration with teachers (Rundgren, 2018).

Different aspects of authenticity have been widely discussed in science education research (Anker-Hansen & Andreé, 2019). One aspect is personal authenticity, which concerns the opportunities students are given to find value and meaning in what they are expected to do and learn (Murphy et al., 2006). According to Lundegård (2018), this relates to how the subject content matter concerns the students and how activities enable students to connect the subject matter content to themselves and their personal lives.

Connection to everyday life is often regarded as essential to enhance students' perception of chemistry education as relevant (Aikenhead, 2006; Broman & Simon, 2015). However, real-life issues often appear to be uncertain, and the 'pure science' learned in schools is often not useful for solving these issues (Aikenhead, 2006; Roth & Barton, 2004). Brickhouse (2011) argues that, 'The knowledge that is taught in schools is often decontextualized, abstract, and difficult to apply to real world contexts' (Brickhouse, 2011, p. 199). To develop meaningful chemistry knowledge, students need support to relate chemistry to their lives and to their role as citizens in society (e.g. Childs, Hayes & O'Dwyer, 2015). The term real-life issue is used in the present study to draw attention to that these are not textbook issues but rather *out of school issues*. Obviously, school is part of the students' real life, but we use *real-life* issue since it is more commonly used than out of school issues.

2.3 Chemistry—a Knowledge Building Practice

Chemistry, as well as the other sciences, is often referred to as an epistemic culture. Epistemic cultures can be described as 'those amalgams of arrangements and mechanics—bonded through affinity, necessity, and historical coincidence—which in a given field, make up *how we know what we know*' (Knorr Cetina, p 1, 1999). This emphasises that it is not only facts and knowledge that make up an academic field but also how the knowledge is built and justified. Nature of Science (NOS) is often used to discuss the epistemology of science in an educational context. NOS is generally regarded as a main purpose of science education. One important aspect of NOS is that scientific knowledge is subject to change, contributing to inherent tentativeness (Schwartz & Lederman, 2008). Related to NOS is *nature of chemistry*, which includes a diversity of perspectives of chemical practices and discussions regarding how chemistry and chemistry education influence society (Vesterinen et al., 2009). This relates to a Bildung-oriented chemistry education, which includes ethical and socio-cultural perspectives (Sjöström, 2013). A Bildung-centred chemistry education aims to contribute to a person's scientific literacy and to support students to develop as critical and actions competent citizens (Sjöström, 2013).

One essential characteristic of scientific literacy is to understand how science works and about the processes where scientific knowledge is constructed (Tala & Vesterinen, 2015). Furthermore, Tala and Vesterinen (2015) argue that students need to understand how scientific knowledge is produced in order to make well-informed decisions on societal and personal science-related issues. The process of producing scientific knowledge is influenced by different aspects, e.g. knowledge is a product of human imagination and creativity; the conducting of investigations and interpretation of data is affected by the scientist's values, knowledge and prior experiences. Furthermore, the society and culture where the investigation takes place will affect the outcomes (Schwartz & Lederman, 2008).

2.4 Towards a Participatory Chemistry Education

To increase student participation, education must pay more attention to students' own questions and ideas and focus less on teaching them to repeat what teachers or other experts have already said and done (Brickhouse, 2011; Roth & Barton, 2004). Education which includes students' own questions might interest a more diverse group of students:

> Perhaps we should be paying more attention to actual scientific competences in complex environments in and out of schools, rather than relying on test scores, and learning about desires and passions of children and adolescents and how these may be linked to science? (Brickhouse, 2011, p. 202)

Basu and Calabrese Barton (2010) have developed a model for a democratic science education through a researcher-teacher-student collaboration. They argue that one way of increasing student authority in the classroom and allowing students' voices to be heard is to present science as tentative, with opportunities to discuss different evidence-based opinions. This allows the students' perspectives and ideas to be valued, instead of more traditional methods where students simply apply facts they are taught by the teacher. The teachers also expressed a desire to value students' funds of knowledge to improve classroom equity. Here the teachers emphasised connecting to students' everyday life experiences to incorporate students' knowledge from outside of school into the education.

Calabrese Barton et al. (2008) discuss *hybrid spaces* where school science discourse and everyday life discourse come together to transform into new knowledge and discourses. Calabrese Barton et al. (2008) write:

> It is in these hybrid spaces where teachers' structural and pedagogical choices allow them to share authority with their students—allowing students to take on, however momentarily, the identity of an expert rather than a novice—and where students can feel what they have to contribute matters and is of value. (Calabrese Barton et al., 2008, p. 98)

2.5 Complexity in Chemistry Education

The notions of *complexity* and *complex issues* are widely used in both science curricula and research in science education (e.g. Sadler et al., 2007). Clear definitions, however, are elusive. Traditionally, complexity in chemistry education has often been discussed in relation to socio-scientific issues (SSI) and environmental issues. Making complexity visible is an important part of science education for citizenship, but this is often neglected within science education (Öhman & Öhman, 2012; Sund, 2015). Complexity is always present in sustainability issues. Complex issues related to the sustainability field are sometimes referred to as wicked problems (Weber & Khademian, 2008). These issues are interdisciplinary, and a diversity of knowledge and perspectives from different fields must be used to understand and analyse the issue. However, in the present study, we turn our focus to the natural sciences, specifically chemistry, and aim to analyse complexity in an activity related to the chemistry content.

The analysis of complexity is often connected to the issue itself, i.e. as the inherent complexity within the issue and how the students perceive this complexity (e.g. Sadler et al., 2007). Another approach is presented by Knain (2015), where the scale of complexity is not found within the issue itself, but rather in how it comes to be expressed in the students' discussions: 'We understand complexity as a quality of the unfolding discourse rather than an inherent characteristic of the issue' (Knain, 2015, p. 113). In our work, we draw on Knain's perspective and focus on how complexity is construed in students' discussions. We explore this through an analysis of the considerations that the students pose in relation to the chemistry content.

Previous studies have shown how students can experience complexity in chemistry issues without exploring real-life contexts. For example, Wheeldon et al. (2012) showed how students experienced complexity within chemistry when working with issues related to chemical equilibrium. However, in the present study, we are interested in analysing how activities in chemistry can contribute to science education for citizenship through real-life issues.

In a previous study, we explored how complexity unfolded in students' discussions regarding sustainability issues (Dudas, Rundgren & Lundegård, 2018). The following aspects of complexity were analysed: areas where chemistry knowledge is required to understand the issue and its potential solutions; conflicting perspectives and values permeate the issue; and, there is uncertainty about the facts, which together with conflicting perspectives and values makes the issue incomplete and contradictory. Through an analysis of the considerations that the students were dealing with in relation to the unfolding complexity, four different categories of considerations emerged, which were used to extract the model below (Table 1).

The present study explores how the previous model evolves when students deal with complexity in an activity based on a *chemistry content issue* relating to human metabolism. We will use *chemistry content issues* to describe issues where the focus is the chemistry content, rather than the societal perspectives on the issues.

3 Aim and Research Questions

An overarching objective of this paper is to explore how chemistry education can contribute to science education for citizenship. Research has shown the importance of dealing with authentic real-life issues and of enabling student encounters with complexity in

Table 1 Didactic model for complexity in students' deliberations regarding sustainability issues (After Dudas et al., 2018)

Factual considerations	
Factual knowledge is required to deal with the consideration	
With sufficient facts	**With insufficient facts**
Factual knowledge is available	Factual knowledge is not (yet) available for students, teachers or scientists
Moral considerations	
Factual knowledge, values and other experiences are required to deal with the consideration	
With sufficient facts	**With insufficient facts**
Factual knowledge is available	Factual knowledge is not (yet) available

chemistry education in order to increase their participation in scientific practices. Therefore, this study aims to analyse how complexity evolves in students' discussions and how this complexity is related to the exploratory nature of chemistry in their discussions. Furthermore, this study aims to investigate how education can be designed to allow students to experience chemistry as a knowledge building practice. One important aspect of this is tentativeness, which we will focus on in this study.

3.1 The Research Questions Are:

RQ1: How can a didactic model for activities supporting students to unfold complexity in chemistry education be developed?
RQ2: How does complexity unfold in students' discussions related to a chemistry content issue?
RQ3: In what ways can activities be designed to enable students to experience aspects of tentativeness in chemistry knowledge?

4 Methods and Analytical Procedure

4.1 Theoretical Framework

This study is based on a pragmatic perspective on learning, grounded in the work of John Dewey. One fundamental pragmatic perspective is that learning can be viewed in terms of actions and that knowledge exists when it is used in a certain context (Cherryholmes, 1999). Therefore, to comprehend a certain content, the content must also be used in a context where it is needed. The meaningfulness of knowledge can be judged from how it is used by the students to deal with an activity. Dewey (1938/1997) argues that encounters with the unpredictable and still unknown establish 'an active quest for information and for production of new ideas' (Dewey, 1938/1997, p. 79). Thus, learning involves testing ideas by reflecting upon their consequences.

4.2 Didactic Modelling

The purpose of didactic modelling is to develop models for teachers to use in didactic design and analysis. A didactic model is often visualised through a conceptual scheme (Wickman, 2012). According to Wickman, Hamza & Lundegård (2020), the phases *extraction*, *mangling* and *exemplification* are included in the development of didactic models. The term mangling draws on Pickering (1995), where it is used to describe how understandings and meanings continually are transformed when used in practice.

In the extraction phase, the processes which are pertinent to the modelling are analysed. In this phase, learning theories are processed together with the data in order to develop a didactic model. In mangling, previously extracted models are used in new contexts for adjustments. An extracted model must be tried and used in practice to prove both its usefulness and limitations. Extraction and mangling are often done simultaneously in cyclic interventions. Exemplification means to use the model in a different context to demonstrate its applicability.

The aim of didactic modelling is not to construct a complete or final model but rather to develop tools that need further and continuous development in practice. Didactic modelling is conducted through close cooperation between theory and practice, teachers and researchers. Seemingly simple models consist of layers of teachers' experiences, didactical research and content knowledge. As the models continually are transformed in practice, the simplicity is a presumption for their use in different contexts. Wickman (2012) writes: 'The words of conceptual schemes continually gain new meaning through the situations in which they are used and through their specific consequences' (p. 130). If the models are too rich and detailed, they will only be useful in specific teaching situations. The teachers' use of didactic models must also include their knowledge about their context, i.e. the age of the students, the student's prior knowledge and the teachers own teaching tradition.

In this study we will use the previously extracted model for complexity in chemistry education (Dudas et al., 2018) with the purpose of mangling the model in a new context. The previous model was extracted from an activity based on a pluralistic perspective on sustainability issues. In the present study, we explore how the model can be mangled in an activity where the chemistry content (i.e. metabolism in the human body) is focused, rather than the societal aspects.

4.3 Analytical Methods

Deliberative educational questions (DEQ) (Lundegård & Wickman, 2007) is used as an analytical tool to discern the considerations the students pose in their deliberation related to a specific content. In their discussions the students encounter gaps which can be filled by new relations. DEQ is used to rephrase the gaps to deliberative questions. The analysed gaps are related to specific purpose of the activity at hand.

DEQ have previously been used to analyse students' choices derived from conflicts of interest in discussions regarding sustainability issues. In the present study we are inspired by Lundegård & Wickmans (2007) work and use DEQ as a method to explore the considerations the students introduce in their encounters with the chemistry content. However, the unit of analysis is not the individuals' utterances but the mutual transactions in the discourse. Lundegård & Wickman (2012) showed how each person's utterance challenged and enabled the other participants to 'take new initiatives in the deliberation' (p. 165) and how this encouraged the students to sketch new ideas or explanations.

4.4 Analytical Procedure

The transcript below shows an example of how the DEQ analysis was conducted in this study. The purpose of the students' discussion was to analyse how factors such as different foods, stress, exercise and rest influence the level of glucose in the blood. The students below had olive oil for breakfast and are discussing the level of glucose in their blood, which has recently been measured.

Excerpt One.

(1) Mark: But why did the blood sugar level increase for me and Ellen after we had eaten fat?
(2) Zoe: F**k!
(3) Peter: This is completely …
(4) Zoe: I am really confused.

(5) Peter: Why should the sugar increase when we eat fat?
(6) Mark: Yeah, that is really strange.
Here a relation is established between sugar is released when eating fat and confusing and strange. This gap can be formulated as the DEQ: Is the increased level of blood sugar after eating fat strange or not?
(7) Zoe: However, there is stored glycogen, which comes out as blood sugar.
Relation: *the increased blood sugar level* and *stored glycogen.*
DEQ 1: *Is stored glycogen part of the explanation for the increasing level?*
(8) Peter: Aww, but the fat?!
(9) Zoe: Wtf does the fat do?
Relation: *the increased blood sugar level and could this happen after eating fat.*
DEQ 2: *Is there a possible relation between intake of fat and the release of stored glycogen?*
(10) Mark: But hey, wait, when the food is eaten, energy is needed to *digest it*, and then *energy is released.*

Relation: *the released energy* and *the digestion of food.*
DEQ 3: *Could it be that the increased level is caused by the body's need to digest?*

Note that the term 'or not' at the end of the first DEQ above implies that this is a question of choice. We assume the 'or not' question to be implicit in all the DEQ presented.

In this study we will use *considerations* to represent what the students need to deal with in order to move on in their discussions and *DEQ* to represent the questions that are discerned as a result of the analysis. However, considerations and DEQ are not interchangeable as the DEQ are not identical to the students' questions, but rather useful analytical tools to make the considerations visible.

4.5 The Setting

4.5.1 Empirical Material

This study was conducted at one upper secondary school in Stockholm in close collaboration with three science teachers. Fifty-six students in the third year of a natural science programme participated. The students were 18–19 years old. Three groups were recorded on video for approximately 10 h each. The teachers put the students together in heterogeneous groups of four to six. A total of fifteen students were recorded. The groups were selected from those students who had given permission to be recorded. We are aware that the students are putting themselves into a vulnerable position as they are asked to share the results from the blood samples. However, the first author knew the students and had been their teacher, and the students knew each other from earlier. Additionally, student participation was voluntarily, and the students could withdraw at any time during the experiment. Our judgment of the situation was that the students did not feel exposed.

4.5.2 Students' Activity

The analysed activity was part of a larger unit covering about 30–40 h in the courses Chemistry 2 and Biology 2. In Sweden the course Chemistry 2 includes biochemistry and specifically: 'The main features of human metabolism at the molecular level' (Swedish National

Agency for Education, 2011). Therefore, this activity relates to both Biology and Chemistry. The purpose of the activity was to use knowledge about metabolism in the human body and different factors influencing glucose level in the blood in a real-life setting. Prior to the activity the students had theory classes on metabolism in Chemistry and Biology. The activity was designed to enable students to experience chemistry as exploratory, where different perspectives on chemistry content could be discussed, thus enabling them to contribute with their own ideas, questions and knowledge.

The activity was conducted in three parts: the students started with the preparation phase where they were informed about the purpose of the activity, i.e. to analyse how different food, stress, exercise and rest influence the level of glucose in the blood. An essential part of the activity was a practical where the students ate a certain food for breakfast then measured the glucose level in their blood. The students prepared the practical by deciding what kind of food to eat for breakfast. The instructions were that the food should be either fat, fast carbohydrates or slow carbohydrates and as pure as possible, e.g. the fat group would eat only olive oil, the fast carbohydrate group only white toast and the slow carbohydrate group only rye porridge. The groups were also instructed to formulate their own research question to correspond with the purpose of the activity, e.g. *How does glucose level change when one eats rye porridge and is exposed to stress, rest or exercise?* These research questions framed the students' work through the activity.

The second part was the practical where the students ate the chosen food at school and measured their glucose levels over 2 h. During this time some of the students exercised, some rested and others were exposed to stress to see if and how these factors influenced glucose levels in the blood.

During the third part, students interpreted and analysed their collected data, i.e. the values and curves describing the changes in glucose levels. The students also designed a scientific poster to present their analysis and results and to answer their research question.

The practical, the analysis of the collected data and the production of the poster were recorded on video. All relevant parts of the discussions were transcribed and analysed with DEQ.

5 Results

The purpose of all discussions was to analyse the glucose level and how this level can be influenced by food, exercise, rest and stress. The excerpts below were chosen since we consider them to illustrate categories emerging in all groups' discussions.

5.1 How Can a Didactic Model for Activities Supporting Students to Unfold Complexity in Chemistry Education Be Developed?

We used the previous model for complexity as an analytical tool to refine the model in the new context. Our approach was to categorise the considerations emerging in the new context into the four previous categories: factual considerations with sufficient facts/insufficient facts and value-based considerations with sufficient facts/insufficient facts (Table 1).

Two different kinds of considerations were discerned: *factual and exploratory considerations*. Both factual and exploratory DEQ could be found in all groups' discussions. In total, 162 DEQ were found in the analysis. Eighty-one of these were factual, and eighty-one were exploratory. The excerpts below illustrate how these two categories emerge in the students' discussions.

5.1.1 Factual Considerations

The factual considerations are considerations to which the answer is known by others (e.g. other students, the teacher or other experts). These usually relate to chemistry content knowledge. In the excerpt below, a group of students who had rye porridge for breakfast are trying to disentangle why one of the student's blood glucose level increased after 15 min.

Excerpt Two.

(1) Sam: But when carbohydrates start to be digested in the mouth by amylase, will one absorb any energy at all?
(2) Anna: Mmm.
(3) Sam: Do you?
(4) Ken: Yes, yes.
(5) Peter: That also gets absorbed into the blood.
(6) Sam: Are you sure?
(7) Ken: Yeah, I remember that you can absorb some glucose in your mouth.
(8) Peter: I suppose that's the reason quick carbohydrates come quickly, since quite a lot gets absorbed into the blood in the mouth already.
(9) Sam: Hmm.
(10) Anna: Yes, exactly.

From this excerpt we formulated the following DEQ:
DEQ 4: Does one absorb any energy when the carbohydrates are digested in the mouth, or not?
DEQ 5: Does the glucose digested in the mouth become absorbed into the blood?
DEQ 6: Is this the explanation for why fast carbohydrates are fast?
We consider DEQ 4–6 to represent factual considerations.

5.1.2 Exploratory Considerations

The exploratory considerations are considerations to which multiple answers or solutions are possible. Exploratory considerations are illustrated through the excerpt below, where a group of students, who had olive oil for breakfast, are analysing the levels of glucose in their blood. The students' hypothesis was that fat should not affect the level of glucose. However, it turns out that Mark's glucose level actually increased after the intake of olive oil and the students are struggling to explain why his glucose level does not follow the predictive curve.

Excerpt Three.

(1) Zoe: How long do you travel to school, where do you live, how do you get to school?
(2) Mark: Well, it's about 30 min; I live in Oakhill.
(3) Zoe: Did anything happen on the metro?
(4) Simon: Did you ride your bike?
(5) Mark: No, I went with the metro.
(6) Zoe: Did anything happen there?
(7) Mark: No …
(8) Zoe: Did you read anything, or did you listen to death metal?
(9) Mark: No, really, nothing special.
(10) Zoe: No butterflies in your stomach …?
(11) Mark: I meet Beatrice (a classmate) on …
(12) Zoe: Ohh, ohh, that's it! (joking)
(13) Mark: … outside the metro and we talked, but I don't know …
(14) Simon: Do you have a pollen allergy?
(15) Mark: Yes …
(16) Everybody: Ohhh!
(17) Mark: Ahhh!
(18) Somebody: That is stress!
(19) Zoe: Are you getting stressed by pollen?
(20) Mark: No, no, but your body is stressed because of the pollen.

From this excerpt we formulated the following DEQ:

DEQ 7: Can we find an explanation to Mark's unexpectedly high levels of blood glucose through an investigation of how he got to school?

DEQ 8: Can we identify an incident on the metro, which might have influenced the inflated level of glucose?

DEQ 9: How can pollen allergy have influenced Mark's blood glucose level?

DEQ 10: Can pollen cause stress in Mark's body?

We consider DEQ 7–9 to represent exploratory considerations and DEQ 10 to represent a factual consideration. Table 2 provides more examples of DEQ found in the discussions.

Table 2 Examples of factual and exploratory DEQ

Factual DEQ	Exploratory DEQ
Are pasta slow or fast carbohydrates?	Do we need to consider the possibility of high levels of cortisol in the morning, or not?
How much time is needed after we eat until we can see the glucose in our blood samples?	Does different kind of exercise influence the levels of glucose in different ways?
Is the difference between fast and slow carbohydrates their structure?	Might the decrease depend on stress caused by the thought of taking the blood sample?
Is sugar quickly digested because it is disaccharides?	How might Vera's intake of cheesecake the night before influenced her glucose levels this morning?
How many disaccharides can be digested at the same time (in the mouth)?	Does the glucose in our blood sample come from released glycogen, or from carbohydrates in our breakfast?
Do we measure glucose in the blood or a different form of it?	

Our analysis indicates that it is possible to merge the factual considerations in the present study with the previous category *factual considerations with sufficient facts*. The exploratory considerations in the present study share many characteristics with factual considerations with insufficient facts. However, the insufficiency and uncertainty have different characteristics in the two contexts. Additionally, by using the notion of *exploratory*, we would like to emphasise the tentativeness and possibilities for further investigations.

The analysis resulted in the following model:

5.2 How does Complexity Unfold in Students' Discussions Related to a Chemistry Content Issue?

In the excerpt below the students, who ate slow carbohydrates (i.e. rye porridge) for breakfast, are discussing why there is a peak in Sam's glucose curve after 45 min.

Excerpt Four.

(1) Sam: But if it happens at exactly the same time?
(2) Ken: Oh, yes.
(3) Sam: And the adrenaline is released.
(4) Anna: And then the insulin is decreased, it is inhibited, and the blood sugar is increased.
(5) Sam: But maybe it takes a little while, it shouldn't increase just like that—poff! — right?
(6) Peter: Yeah.
(7) Sam: Because it doesn't happen directly.
(8) Ken: But maybe it was already on the way up, like, when it was at the bottom … here (points on the graph) it started to curve up …
(9) Peter: At the same time as the slow carbohydrates probably came down to …
(10) Ken: But it could also be that …
(11) Sam: Yes, exactly.
(12) Peter: … small intestine.
(13) Sam: No, it could be like that.
(14) Anna: Doesn't it take longer?
(15) Peter: It did take 45 min, that is a long time.
(16) Anna: Yes, that is quite long.
(17) Ken: Well, can we then say that this peak is connected to stress, in combination with the food starting to be digested …?
(18) Anna: But I have heard that stress inhibits the digestion, so, so …

From this excerpt we formulated the following DEQ:

DEQ 11: Does adrenaline cause a decrease of insulin?

DEQ 12: Is that a fast process?

DEQ 13: Did the effect of adrenaline coincide with the appearance of glucose from slow carbohydrates in the blood?

DEQ 14: Might stress together with food cause this 'peak'?

The excerpt above shows how the unpredictable and unexpected results in this real-life issue enable students to pose different considerations in relation to the chemistry content.

Some of these are related to factual knowledge (DEQ 11 & 12) and others to the inherent tentativeness in the issues (DEQ 13 & 14). This combination of factual and exploratory considerations contributes to the unfolding complexity in the students' discussion.

5.3 In What Ways Can Activities Be Designed to Enable Students to Experience Aspects of Tentativeness in Chemistry Knowledge?

The results indicate that one way to enable students to experience chemistry as tentative can be to design activities where the students encounter unpredictable or inexplicable results. In the present study, this caused uncertainty regarding how to make the chemistry content knowledge useful when dealing with real-life issues. This enabled the students to introduce exploratory considerations. As more than one answer is possible, the students can experience chemistry as tentative. This is illustrated in excerpt three, where the students contributed with a diversity of explanations about how different everyday factors might have influenced Mark's blood glucose level. Therefore, drawing on real-life issues seems to be a way to enable students to experience chemistry as exploratory with inherent tentative aspects.

5.4 Summary of Results

Two different kinds of considerations were discerned in the students' discussions—factual and exploratory considerations. The new model for complexity consists of these two categories. Furthermore, the results indicate that to base activities in real-life issues with inherent uncertainty in how to use chemistry content knowledge might be a worthwhile approach to enable students to unfold complexity and to experience chemistry as exploratory.

6 Discussion and Conclusions

In this study, we propose a refined model for complexity in students' discussions consisting of factual/exploratory considerations (Table 3). The purpose of the model is to support teachers in design and analytical reflections on activities aiming to enable students to unfold inherent complexity in chemistry content issues. We explore complexity as it unfolds in the students' discussions (Knain, 2015). The analysis shows how the students facilitate complexity through the considerations they pose in relation to the chemistry content in the discussions. The activity draws on a Vision II perspective through a real-life issue where chemistry knowledge is needed. This kind of activities often leads the students' discussions down unpredictable paths (Roberts, 2007). Furthermore, Dewey (1938/1997) emphasises the importance of encounters with the unknown, as he argues that

Table 3 Didactic model for complexity in students' discussions

Factual considerations	Exploratory considerations
Considerations with answers known by others	Considerations with multiple answers
Example: Does adrenaline cause a decrease of insulin?	Example: Did the effect of adrenaline coincide with the appearance of glucose from slow carbohydrates in the blood?

these are the foundation of new ideas. As complexity is closely related to uncertainty, this study indicates that the students unfold the inherent complexity in real-life issues through the exploratory considerations they pose. Factual considerations do not explicitly enhance complexity from an uncertainty perspective and a discussion permeated merely by factual considerations can hardly be regarded as complex due to a lack of uncertainty.

Factual considerations often relate to the 'pure' chemistry content and are in line with how scientific knowledge has traditionally been presented in schools, i.e. as absolute, with one right answer, and unaffected by values, or cultural and societal perspectives (e.g. Aikenhead, 2006; Brickhouse, 2011; Roth & Barton, 2004). They also correspond to the tradition of students being expected (and thus limited) to repeat and learn what teachers and other experts already know (Brickhouse, 2011). This has preserved the image of science as a subject with irrefutable answers and devoid of creativity, leaving many students feeling alienated. Nevertheless, chemistry content knowledge is essential for scientific literacy—'everybody agrees that students can't be scientifically literate if they don't know any science subject matter' (Roberts, 2007, p. 735). Furthermore, factual considerations are often needed to disentangle the chemistry content knowledge related to the exploratory considerations. Consequently, factual considerations are an indispensable part of chemistry education, but if students only encounter this kind of science, there is a risk of maintaining the image of science as non-exploratory, uniform and absolute.

Exploratory considerations emerge when students encounter uncertainty about how to make chemistry knowledge meaningful in authentic contexts. It is not about insufficient factual knowledge, but rather related to issues where different chemistry knowledge-based answers or explanations are possible. The discussion in excerpt three illustrates how the students negotiate the use and understanding of the chemistry content in relation to the real-life issue at hand. Here, the students are allowed to pose their own ideas, based on chemistry content knowledge, to solve the problem: **Simon**: *Did you ride your bike?* (Chemistry knowledge: adrenaline affects the level of glucose); **Zoe***: Did you read anything, or did you listen to death metal?* (Chemistry knowledge: stress affects the level of glucose); **Simon**: *Do you have a pollen allergy?* (Chemistry knowledge: pollen might cause stress).

One aspect of science education for citizenship is to facilitate student encounters with real-life issues which they are likely to encounter as citizens (Roberts, 2007). Furthermore, it is often claimed that to enhance the authenticity and relevance of chemistry education, students need support to make connections between chemistry content and their everyday lives (Childs et al., 2015). The students in the present study often demonstrate theoretical knowledge about how carbohydrates, stress and adrenaline affect the level of glucose. But when it comes to real-life contexts, this knowledge is not easily applied to an explanation of how and why blood glucose levels are changing (Brickhouse, 2011; Roth & Barton, 2004). This is illustrated in excerpt one, where the students 'know' that blood glucose levels should not be affected by the intake of fat. The emerging conflict between the chemistry content knowledge (fat should not affect the level of glucose) and the real-life experience (increased glucose level after intake of fat) introduces an uncertainty. Thus, the students need to deal with exploratory considerations regarding what might be possible explanations for the increased blood sugar level after Mark and Ellen ate fat. The results imply that when students have difficulties to use scientific knowledge to interpret the data, they turn to real-life experiences to find explanations.

In order to enable students to contribute to positive and responsible changes in society, we need to develop a science education in which students are willing to participate (Brickhouse & Kittleson, 2006; Elmose & Roth, 2005). Exploratory considerations seem to facilitate hybrid spaces, where a consolidation of chemistry content knowledge and the students' everyday experiences can be transformed into new knowledge. Hybrid spaces can also increase student authority in the classroom by regarding their voices as worthwhile, which is important to enhance student participation in science education (Basu & Calabrese Barton, 2010; Brickhouse, 2011; Calabrese Barton et al., 2008). The tentativeness in 5.1.2 could also be a way to enable the students to participate through their own funds of knowledge and thereby increase their participation in chemistry education (Basu & Calabrese Barton, 2010). In the present study, the students are moving on from what they already know to create new knowledge regarding specific contexts where knowledge about metabolism is needed. Here, we would like to stress that it is not about abandoning scientific knowledge but rather about giving students opportunities to use and create their own knowledge in a specific context.

It is often claimed that the science taught in school is presenting a fake image of how knowledge is construed in science (Brickhouse, 2011). One important aspect of chemistry as a knowledge building practice is the inherent tentativeness. Activities supporting students to unfold this tentativeness through exploratory considerations might be one approach to increase students' understanding of NOS and, furthermore, enable students to experience chemistry as a knowledge building practice. As the exploratory considerations are investigable, one approach to relate chemistry education to chemistry as a knowledge building practice might be to let students construct investigable questions and conduct practical inquiries from exploratory considerations. Then the students would not only learn scientific content but also the knowledge building aspects of science. However, this is not the objective of this study and needs to be further analysed. Experiencing aspects of tentativeness in scientific knowledge have been shown to increase understanding of NOS and thereby contribute to development of Bildung and scientific literacy (Schwartz & Lederman, 2008; Sjöström, 2013). In excerpt three, the students draw on their experiences about how they got to school and how this might have influenced the level of glucose. The students advance from their own considerations in relation to the chemistry content to develop their own ideas throughout the activity. These considerations can also challenge and enable other students to try new ideas and explanations (Lundegård & Wickman, 2012). From a pragmatic point of view, learning content must also be based on the use of that content in a situation where it is needed (Cherryholmes, 1999). In the present study, chemistry knowledge is substantially required when the students are dealing with their own considerations. Furthermore, the chemistry knowledge becomes meaningful through the activity (Cherryholmes, 1999).

The factual and exploratory considerations deal with epistemology. Accordingly, these categories in the models engage with how we model chemistry education to deal with understandings of how reality works. In the present study, there was an absence of moral-related considerations. A possible explanation might be that values and moral issues were not explicitly emphasised in this activity. However, from a pragmatic perspective, subject matter content is inseparable from values. The students do not only learn entire facts but also the accompanied values that come with the facts (Dewey, 1938/1997). Thus, the students are continuously making choices about how to proceed, how to act and what to focus on; all these acts involve values. Hence, a value-free education is difficult to imagine (Wickman, 2004). We regard the value-related categories in the previous model as dealing with moral issues, i.e. how things ought to be or how we ought to act. Thus, the value-related categories in the previous model regard how we should model education to support moral considerations. The present activity did not explicitly relate to how one ought to act.

The students were not encouraged to position themselves or argue for different opinions in this activity. The activity was not designed to focus on the societal or moral perspectives of metabolism (e.g. obesity or diabetes). This might be a possible explanation for the lack of moral-related considerations in the present study. It could, however, be viable to extend the activity to include these perspectives as well.

This paper is based on one study in one upper secondary school, which implies that more studies are needed to support the claims made here. The refined model in the present study is extracted from students' discussions and has not yet been used together with teachers. In future research, the model can be further explored in different contexts in cooperation with teachers. This would mangle the model further and develop scaffolding material for teachers. Thereby, the model can also be more exemplified and useful for teachers.

7 Conclusions and Didactic Implications

To support students to unfold complexity in chemistry content issues, activities need to be designed to include both factual and exploratory considerations. Furthermore, the unfolding complexity can support students to experience chemistry as a knowledge building practice. Activities based on real-life issues invite the unpredictability and uncertainty needed for experiencing the exploratory nature of chemistry. These issues might enable students to experience aspects of tentativeness in chemistry and thereby increase their understanding of NOS and chemistry as a knowledge building practice.

8 Conflict of Interest

The authors declare that they have no conflict of interest.

Funding Open access funding provided by Stockholm University.

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