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University Students' Reflections on Representations in Genetics and Stereochemistry Revealed by a Focus Group Approach

Abstract

Genetics and organic chemistry are areas of science that students regard as difficult to learn. Part of this difficulty is derived from the disciplines having representations as part of their discourses. In order to optimally support students' meaning-making, teachers need to use representations to structure the meaning-making experience in thoughtful ways that consider the variation in students' prior knowledge. Using a focus group setting, we explored 43 university students' reasoning on representations in introductory chemistry and genetics courses. Our analysis of eight focus group discussions revealed how students can construct somewhat bewildered relations with disciplinary-specific representations. The students stated that they preferred familiar representations, but without asserting the meaning-making affordances of those representations. Also, the students were highly aware of the

affordances of certain representations, but nonetheless chose not to use those representations in their problem solving. We suggest that an effective representation is one that, to some degree, is familiar to the students, but at the same time is challenging and not too closely related to "the usual one". The focus group discussions led the students to become more aware of their own and others ways of interpreting different representations. Furthermore, feedback from the students' focus group discussions enhanced the teachers' awareness of the students' prior knowledge and limitations in students' representational literacy. Consequently, we posit that a focus group setting can be used in a university context to promote both student meaning-making and teacher professional development in a fruitful way.

Introduction

Genetics and organic chemistry are areas of science that pose significant learning difficulties (Tsui & Treagust, 2010; Wu & Shah, 2004). These subjects deal with complex sub-microscopic entities that call for complicated sets of representations that often are experienced as abstract. A large array of disciplinary representations is used to share knowledge within science disciplines, and these representations are critical in science education for enabling students to achieve "fluency" in the disciplinary discourse (Airey & Linder, 2009; Nichols, Hanan, & Ranasinghe, 2013). Taking such a perspective on meaning-making means that effective science teaching becomes about fostering disciplinary literacy, where disciplinary literacy is defined as "the ability to appropriately participate in the communicative practices of a discipline" (Airey, 2011). Put another way, disciplinary literacy is about attaining an understanding of the ways in which knowledge is produced and disseminated within disciplines such as genetics and chemistry, and effective meaning-making means becoming competent in the interpretation, application and production of disciplinary knowledge.

Typically, university educational programs consist of several separate courses, from which the students are expected to build a holistic and deep knowledge. In these courses, different representations are often used for the same or similar phenomena, but their different meaning-making affordances are often hidden for the students (Fredlund, Airey, & Linder, 2012; Linder, 2013). Sometimes representations are also used in an incoherent or misleading way, both by teachers and in textbooks, e.g., symbols are not fully explained, metaphors are ambiguously used, and hybrid models (combination of models based on different theories) are used without clarification. As discussed by Anderson, Schönborn, du Plessis, Gupthar, & Hull (2013), this can give rise to conceptual and reasoning problems for the students.

As students may have difficulties in understanding, translating and using representations in a productive way, i.e., seeing them and using them as the discipline does, it has been argued that teachers have an important role in the development of students' disciplinary literacy (Chittleborough & Treagust, 2008; Kozma & Russell, 1997; Tsui & Treagust, 2013). There are different views on how learning is achieved in science education, from an individual constructivist view to a sociocultural view, as discussed by Leach and Scott (2003). From a sociocultural perspective, learning takes place in socially situated contexts, such as interactions between teachers and students, and between students. Examples of educational settings that support such interactivity are small group teaching and peer discussion (Lemke, 1990; Smith et al., 2009). We used a focus group setting for our data analysis. On the one hand such settings have been argued to have the potential to stimulate interaction and learning in a similar way as problem based-learning (PBL; Wibeck, Åbrandt Dahlgren, & Öberg, 2007). On the other hand, focus group settings have been shown to be able to uncover the differences and similarities in the unique experiences and perceptions of the various group members (Winlow, Simm, Marvell, & Schaaf, 2013).

University teaching is mostly carried out by researchers who are specialists in specific course topics. While they may have deep knowledge of their subject, their approach to teaching will range from information transfer to attempting some kind of "conceptual change" (Prosser & Trigwell, 1999). In general, science teachers often have a more information transfer/teacher-focused approach to teaching than teachers from the so-called "soft" disciplines (Lindblom-Ylänne, Trigwell, Nevgi, & Ashwin, 2006). This calls for intervention because such a teacher focused approach is more likely to evoke a surface approach to learning (Trigwell, 2012). Even teachers who are recognized as being "thoughtful about their teaching" often use disciplinary representations from textbooks and other sources with arguments such as "this representation works for me", or "this is a typical representation", i.e., they chose and use representations without much educational reflection (Linder, Wikman, & Linder, 2011).

University teachers in science faculties are expected to introduce complex topics in a way that makes sense to students with a varying background (Schuetze & Slowey, 2002) and sometimes limited prior knowledge, both with regard to content and how to "read" representations. Teachers need to constitute their teaching in ways that facilitate the emergence of good insight into the variation of students' prior knowledge and how they are making sense of current teaching sequences.

In this paper, we focus on students' reflections on representations in genetics and stereochemistry:

- What are perceived as main representational factors facilitating meaning-making in introductory genetics and stereochemistry?
- What supporting factors are important for making representations meaningful?

In addition, we reflect on the focus group approach in order to evaluate its possibilities as pedagogical approach in university science education.

Method

To explore the research questions, we examined university students' reasoning on disciplinary specific representations *per se*, and when using representations in problem solving. A focus group setting was chosen since it has the potential to stimulate interaction and participants' discussions, allowing the researcher to identify hidden points of interest (Winlow et al., 2013), see also Introduction.

The students that volunteered to take part in the study were enrolled in either a course on cell biology (genetics) or one on organic chemistry. The courses constituted parts of the first or second year of study on different university science programmes (biology, biomedicine, pharmacy, food science). The representations in focus (meiosis, Mendelian genetics, and stereochemistry) had been included in lectures given by the respective specialist teacher (see below) before the focus group sessions. In stereochemistry, an exercise on 3D-modelling had also taken place prior to the focus group sessions.

Two experienced university science teachers, with more than 20 years of teaching and research on genetics and organic chemistry, respectively, together collected the data. Each of the teachers was a specialist in one of the subjects under study and acted as both a specialist and a non-specialist, the latter when acting as moderator for the focus group discussions. The non-specialist teacher also took field notes during these discussions. This research design meant that the participating teachers moderated the focus group discussions in the other teacher's discipline and not in their own.

During the focus group sessions (45-60 min each), students were asked both to reflect on disciplinary representations and to solve subject-specific problems (Mendelian inheritance, stereochemistry). They were also asked questions on problem solving strategies and while attempting this task their interactions with representations were video and audio recorded. The recordings were transcribed verbatim. This data was collected across three consecutive years. In total, eight groups with four to eight students per group took part in the study – the total number of participating students was 43 (34 female and 19 male).

The transcribed focus group discussions (consisting of speech, gestures and interaction with equipment) together with field notes were, using an iterative approach, coded and categorized (Table 1) using the software NVivo (NVivo10, 2012), which offers a reliable and accurate workspace for qualitative analysis. A thematic analysis was carried out following Braun and Clarke (2006). During the analysis, both the specialist and the non-specialist teacher were involved in order to highlight both general and discipline-specific results. The codes, categories and themes were refined through discussion until consensus was reached. The excerpts presented herein were translated from Swedish by the two participating teachers. Ethical recommendations from the Swedish Research Council (Hermerén, 2011) were followed throughout the study.

Results

The analysis of students' discussions in the focus groups revealed three main themes: students' opinions on the *design of representations and meaning-making* when interacting with representations, *students' opinions versus their actions*, and *students' need for guidance* when striving to make meaning of representations. The identified codes, categories and themes are shown in Table 1. We also looked for similarities and differences between the disciplines. Most studies in the literature tend to focus on one discipline at a time – in our design we chose to include two scientific subjects with the intention of comparing the results. In addition, we report several comments concerning the focus group setting.

Table 1. Codes, categories and themes employed in the analysis of the data.

Code	Category	Theme
Colouring or shape of representation Information density in representation Complexity of representation	Design	Design of representation and meaning-making
Familiarity of representation Recognition of representation	Acquaintance	
Analysis of representation (Un)certainty in interpretation of representation Description of representation Insight into subject	Meaning-making	
Preference of representation Opinions regarding representation	Views	Students' opinions versus actions
Actions employing representation	Activity	
Support requirements Educational expectations	Student expectations	Students' need of guidance
(Un)familiarity with content (Un)able to make meaning Relation to students' lived world	Previous knowledge	

Design of representations and meaning-making

In general, students expressed that they preferred representations that they were already familiar with. They described how they preferred a specific representation because they identified it as "the normal" representation for a certain phenomenon.

> *It looks too complicated... that's not the normal picture you have of mitosis, is it?* (Genetics)

However, recognizing a given representation as familiar did not necessarily mean that they were able to identify the key concepts that it afforded, or that they could explain it to one another. For example, only one or a few chromosome pairs (in contrast with the 23 chromosome pairs in a human somatic cell) are given in the representations that are commonly found illustrating cell division (mitosis and meiosis). This caused confusion for several of the students.

> *But if you look, you know... [silently]... where does everything, like, fit in?* (Genetics)

> *I have brought this question along the entire year... I have never heard anyone say that this not a human cell, that this is an example with only two... pairs of chromosomes, this is an example. We have 23. How does this really work, since I didn't know that this wasn't a human cell?* (Genetics)

Even when the students claimed that they "understood" a particular representation, they had problems in relating those representations to their lived world and to constitute meaning from them.

> *But, can an ordinary cell undergo both, does it undergo mitosis and meiosis?* (Genetics)

> *I would say that the dashed [bond] could be [pointing] forwards, as well as backwards.* (Chemistry)

The students expressed a preference for figurative representations over more abstract-looking ones, for example, they favoured pictorial representations over diagrams.

> *That one is much better since there are [visible] cells.* (Genetics)

They also claimed that colours and form are of importance for how they interpret the message in a representation.

> *Maybe, you could have used red [as a marker] for the cells that are flawed.* (Genetics)

> *The red one is oxygen, isn't it?* (Chemistry)

> *But for some, red usually means "error", so yellow is perhaps the wrong choice of colour here.* (Genetics)

When faced with information-dense representations, the students did not know where to begin to interpret the representation and then they typically focused on the surface features and details of lesser importance.

> *But if you get a picture like that you will think, kind of, well, where do I begin [to read the figure]? Then you think, I'll deal with it later, and then you never do. Especially if it is such a muddled picture, when you feel as you could not be bothered with trying to familiarize yourself with it. Although it might not really be that complicated.* (Genetics)

> *If you get too much to look at, then you will just stare, without thinking.* (Chemistry)

Students' opinions versus actions

Regarding stereochemistry, several students stated that they experienced difficulties when trying to transfer information from a two-dimensional format to a three-dimensional molecular model. When questioned about the usefulness of ball-and-stick 3D molecular models, the students described how these were easier for them to interpret than 2D images and that the 3D models were important for meaning-making during lectures and problem solving sessions on stereochemistry that were led by a teacher. However, they felt it was unnecessary to construct their own hands-on models when solving problems on their own. Moreover, the students were of the opinion that it was important to be able to solve stereo-chemical problems with only pen and paper since they could not be sure that they had access to molecular models in all problem solving situations.

In genetics, the students stated that although they preferred a representation that they could relate to in their lived world, their personal relation to the representation did not matter.

> *If you can make an association to something commonplace, so that you kind of feel: "I have seen this, I know how this works"… if you see a black Labrador [dog], yes…* (Genetics)

> *It doesn't matter if it is about plants or not.* (Genetics)

However, the discussion was much more lively and engaged when a representation illustrating the inheritance of coat colour in dogs was used instead of the traditional one, showing the inheritance of flower colour in garden peas, originally published by Gregor Mendel. In addition to discussing the meaning of the representation (Mendelian inheritance of coat colour), the students discussed the appearance and character of dogs they knew.

Students' need of guidance

In order to grasp the intended signification of representations, the students claimed that they needed help from e.g., written text and/or the teacher.

> *Either [the teacher should] interpret [the representation] or there should be an interpretation given in a text or similar, since interpreting such an image can be difficult.* (Genetics)

> *But how do you get there? Do you mean that you can see that one thing is at the same place?* (Chemistry)

The students frequently had problems making meaning of the representations, i.e., relating a representation to the phenomena that it was intended to illustrate.

> *But then it is different [scales] on the axes, there it is DNA content and there it is chromosome number, it's a little funny that it is not the same …* (Genetics)

> *You can turn them [the molecular models] upside down, too. That is one more thing to think about.* (Chemistry)

Students also expressed a need for guidance and support on how to see the relation between a particular representation and their lived world.

> *Yes, otherwise it's like "Yeah, this happens on paper, but I don't understand what it means!" You need to have, yes, a link, "Aha! That's what happening! Otherwise… aha, it happens like this, but, yeah, so what? It doesn't mean a thing.* (Genetics)

But, I think it's useful that the teacher mentions this... Firstly, there was someone that raised a question on... and XXY, and I think it is good that the teacher brings this up, it gives you perspective on what happens [when chromosomes do not separate in meiosis]. (Genetics)

However, students stated that their teachers in general rarely explained for the students – in an understandable way – how the representations should be made sense of.

Similarities and differences between chemistry and genetics students' views

Students from both courses described how they felt that what they saw as a ”clear” design was important (see Design of representations and meaning-making). That is, the students wanted unembellished representations with a limited amount of details, a consequent use of colours, and an accompanying explanatory text that they found adaptable to their prior knowledge. Furthermore, they found it more advantageous to split an information dense representation into two separate parts, in order to minimize the informational crowdedness.

Students also described how they needed support and guidance from their teachers in order to make appropriate meaning from the representations, irrespective of discipline (see Students' need of guidance). They also found that the group discussions were important in supporting their meaning-making both in genetics and in stereochemistry.

Within both disciplines it was observed that there was a discrepancy between the students' actual familiarity with different representations and the familiarity with representations that the teacher expected to find among the students. Also, the students seemed to be uncertain of how to interpret general concepts that they arguably should be familiar with.

If it is identical, it is exactly the same... or? (Chemistry)

Some discipline specific difficulties could also be identified. For instance, in genetics, students had problems distinguishing between different organizational levels, and confused recombination during meiosis (crossing-over between homologous chromosomes) with fertilization (fusion of gametes).

I thought this [recombination] happens between a man and a woman, doesn't it? (Genetics)

Maybe as a consequence, the students also had problems identifying the different generations in the traditional representations illustrating Mendelian inheritance.

Interestingly, students that later passed the examination, were not aware of the fact that gametes carry one chromosome copy of each chromosome pair, not only a sex chromosome.

Yes, the meiosis is just concerned with the final pair of chromosomes... where the sex chromosomes segregate... (Genetics)

Other students were unaware that mitosis is the process that leads to the formation of new cells in the growing embryo.

But, when two gametes fuse at fertilization, they form a zygote, ... grow to an embryo, but... How are the autosomal cells formed from the zygote? (Genetics)

In chemistry, the students were uncertain about how to interpret several discipline specific concepts that had been in the course. For instance, they overlooked that diastereomers by definition cannot overlap with each other and that *cis*/*trans*-isomerism may be observed both in unsaturated and cyclic substances.

> *They [the diastereomers] can overlap with each other! Isn't it so? Yes... No...* (Chemistry)

> *You can get cis and trans only when you have a double bond.* (Chemistry)

When considering chemistry, a majority of the students had used 3D models in their previous studies before entering university, but they were unaccustomed to using molecular models as a problem solving tool and had difficulties in transferring information from 2D to 3D, and vice versa.

Experiences from the focus group setting

The focus group discussions seemed to promote the students' meaning-making, and enhanced their awareness of their own and others interpretation of a specific representation.

> *What does it mean, why does it say..? ... Aha, first you are a gamete, then a zygote, then... (Genetics)*

> *Oh, I'm shouting out a lot of wrong answers... now, I have to be quiet!* (Chemistry)

> *If I can explain something to someone else, I truly understand it myself.* (Chemistry)

The students found that the allotted time for the focus group discussions, one hour, passed surprisingly quickly.

> *Now the other group is coming, so we have to finish.* (Focus group moderator)
> *Should we stop already?* (Student)

When asked to take part in a second focus group discussion in the other subject (first chemistry, then genetics), the students did not hesitate to volunteer and spontaneously expressed that they found their previous experience beneficial with regard to their meaning-making.

> *Of course we will take part in this [the focus group discussion]. Come on, the last [discussion] was really good.*

Discussion and conclusions

Students had difficulties in gaining access to the potential meaning-making affordances of a particular representation, e.g., to "see" 3D structures, and using that affordance to formulate a useful visualization. Also, students stated that they preferred representations that they were familiar with, but without identifying the meaning-making affordances of those representations. This is in accordance with the results of Fredlund et al. (2012), who found that students' first choice was the representation that was most frequent in their textbooks, not necessarily the most appropriate one for the task at hand. Our conclusion is that students are faced with multiple challenges when exposed to representations they are not familiar with and that get used by teachers with limited insight into student meaning-making and possibilities to meaning-making with the aid of representations. From a teacher perspective, we conclude that the choice and use of representations need to be thoroughly reflected upon.

We suggest that an effective representation is one that, to some degree, is familiar to the students, but at the same time not too closely related to "the usual one", i.e., it is challenging in that the students are stimulated to reflect. This is in accordance with Höst, Schönborn, & Lundin Palmerius (2012) that state that "a representation that students consider most challenging to use may still effectively communicate the intended molecular phenomenon". The designs that the students' claimed that they preferred, i.e., figurative representations containing a limited amount of details, a consequent use of colours, and an accompanying explanatory text that is adapted to their prior knowledge, are in line with previous findings by other authors, e.g. Pintó & Ametller (2002).

In our study, the students claimed that they needed support and guidance on how to interpret representations, but that teachers seldom gave the necessary support (see See Students' need of guidance). We conclude that an important issue seems to be how a representation is presented and employed in the teaching situation. To guide the teacher on how to choose and use representations, the affordances of different representations might be analysed using the conceptual-reasoning-mode (CRM) model, suggested by Anderson et al. (2013) when analysing students' reasoning abilities and problem solving with representations.

Our results (see Experiences from the focus group setting) show that the students felt that focus group discussions improved their meaning-making. It is previously shown that small group teaching and peer discussion can enhance student understanding through the process of group discussions and debate (e.g. Smith et al., 2009). Focus group is a research method approach that has similarities with PBL tutor groups (Wibeck et al., 2007). Both focus and PBL groups discuss a defined subject under the guidance of a tutor/moderator. In accordance with the detached role of the PBL tutor, the specialist teacher was in our study not present during the discussions. This seemed to relax the students and allowed for a more genuine response in their statements and a detailed elucidation of their needs in this respect. As for PBL tutor groups, the participating students in our study enhanced their meaning-making through the peer discussions. An attractive attribute of focus group discussions is the strong influence that the participants may have in the shaping of the research project (Winlow et al., 2013), here, the focus group sessions.

We propose that representational knowledge should receive more attention in university pedagogy, and ought to be included in the pedagogical training of university teachers, and most likely also in teacher education. From the focus group discussions, we conclude that students need in-depth training in how to interpret and use representations in meaning-making. Furthermore, it is essential that teachers have a deep understanding of how to support the students' efforts in gaining representational knowledge, as suggested by Park & Chen (2012).

The data was also used by the teachers performing this study to inform their teaching in subsequent courses. One experience made by the teachers during the analysis was the importance of discussing the meaning of representations – even those considered non-problematic and easily understandable by the teacher – and engaging students to use discipline specific representations more often, which is in accordance with Kozma & Russell (1997) and Nichols et al. (2013). Furthermore, it was also evident that the students could benefit from coming in contact with even a greater variety of representations than the teacher initially had envisioned, as also suggested by Airey & Linder (2009). The variation called for here, refers to both multiple representations in a particular mode and representations in different modes.

To ensure the trustworthiness of the results, the following was considered. The focus group approach is well suited to reveal differences and similarities in the perceptions of the various group members (Winslow et al., 2013). To ensure a broad range of informants' views, the data in our study was collected over three consecutive years, involving students from four different study programs. The focus group discussions were performed in a relaxed atmosphere; the students volunteered to take part in the study, and a non-specialist teacher acted as focus group moderator in a similar way as the base group moderator within PBL (Wibeck et al., 2007). In addition, the recorded focus group discussions were transcribed after examination of the actual course, i.e., the students were assured that they could speak freely and that the group discussions were not part of their examination. For each focus group, the recordings were transcribed verbatim by the specialist teacher, but the transcripts were scrutinized by both teachers, and the thematic analysis was discussed with the other co-authors until consensus. Most earlier studies that have examined students' reflections on representations have focused on compulsory or secondary school, but several of the observations we have made for university students are in accordance with these, indicating their generalizability.

The focus group discussions gave teachers direct feedback from their students and enriched the teacher's awareness of the students' prior content and representational knowledge and meaning-making. We suggest that the focus group approach is well suited for a university setting and can be adopted by colleagues in different subjects. In contrast to compulsory and upper secondary school, university teachers seldom teach similar or identical courses, thus making team teaching and a Learning Study methodology (Marton & Tsui, 2004) more difficult to realize. The focus group approach can be used to promote both the development of teachers' professional knowledge and to promote student meaning-making and metacognitive awareness. The focus group approach gives teachers detailed information concerning their students' meaning-making difficulties. Also, compared to recorded lectures, analysis of recorded focus group discussions gives a direct feedback to the individual teacher on how his/her teaching has made meaning to the students.

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