Teachers' approaches to genetics teaching mirror their perceptions of teaching controversial, societal and sensitive issues

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Disclosure of conflicts of interest: T.A. has participated in writing biology textbooks for upper-secondary school biology for eOppi Oy and has received monetary compensation. None of the teachers involved in this study used biology textbooks from eOppi Oy.

Abstract

The skills to understand genetic phenomena and transfer knowledge to real world situations are an important part of 21st century scientific literacy. While socio-scientific issues (SSI) are emphasized and impediments to considering SSI are widely studied, science teachers have low interest in adopting SSI in teaching. Little is known about how teachers choose content for their teaching, although this is the process in which curricula translates to teaching practice. We studied how teachers choose content for biology courses on cells, heredity, and biotechnology by interviewing ten Finnish upper-secondary school teachers. We asked which content they perceived as the most important and studied how they described teaching genetically modified organisms, hereditary disorders, and complex human traits. We used content analysis to build a tentative model of variables influencing teachers' choices. We found three main categories of the most important contents: development of phenotype, inheritance and continuity, and gene function. While teachers mentioned that SSI are important, they were never mentioned among the important contexts. Teachers differed in how they described teaching: some embraced human-related content while others described avoidance due to content or pedagogy-related issues. The tentative model of teachers' choices included national-level factors, which were common to all teachers, school-level factors as the local context and personal-level factors. We classified teachers' perceptions to *Developmental*, *Structural* and *Hereditary approaches in genetics teaching* which contained not only the perceptions of the most important content, but also teacher inclinations towards teaching human genetics and perceptions of students' interest in different topics. Teachers' perceptions were strongly linked with teachers' likelihood to discuss human genetics. Experience played a part in which approach teachers had, and contrary to previous research, the less experienced teachers were most open to discussing human genetics. Our results suggest that curriculum is an important tool encouraging teachers to adopt SSI-oriented teaching.

Keywords: *genetics content, teaching approach, biology education, socio-scientific issues*

Introduction

Socio-scientific issues (SSI) have been suggested to empower students to reflect on the effects and importance of genetics in the world around them (Lederman, Antink, & Bartos, 2014; Lewis & Leach, 2006; Zeidler, Walker, Ackett, & Simmons, 2002). It is argued that SSI form a crucial part of scientific literacy (Zeidler, Sadler, Simmons, & Howes, 2005) and that SSI would increase the students' interest in studying and motivation to study genetics (Khishfe, 2014). Nevertheless, teachers have been resistant to adopt SSI in their teaching (Lazarowitz & Bloch, 2005; Lee, Abd-El-Khalick, & Choi, 2006). This problem seems to be pervasive not only in biology education, but also in other subjects, including natural and social sciences (Cross & Price, 1996; Lee & Witz, 2009; Misco & Tseng, 2017). Several reasons have been proposed to explain this phenomenon, including limitations of the curriculum or assessment techniques, teacher pedagogical competence and that teachers' lack of support for the merits of SSI discussions as pertinent to specific learning subjects (Bryce & Gray, 2004; Gray & Bryce, 2006; Lewis & Leach, 2006; Newton, Driver, & Osborne, 1999).

While teachers' attitudes towards different teaching methods related to SSI have been widely studied, there is far less research on how teachers argue how they choose their actual content or examples that they use in teaching practice. In the context of SSI, a recent study suggested that biology teachers give primacy to biological content over societal contextualization (Tidemand & Nielsen, 2017). To understand teacher attitudes towards teaching genetics, we explored how teachers argue in favor of which content they teach in genetics courses. Within a larger research project on how students and teachers understand gene structure and function, we interviewed upper-secondary school biology teachers on how they perceive and teach gene structure and function. We aimed to explore how upper secondary school teachers choose content in genetics education by examining their answers to questions about how they teach three different themes: genetically modified organisms, human hereditary disorders and complex human traits, such as intelligence. Our research questions were:

1. How do teachers interpret the main theme of genetics courses?
2. Which content do teachers teach?
3. Which content do teachers try to avoid?
4. How do teachers argue in support of their choice of content?

Theoretical background

Teachers choosing and avoiding content

Previous research does suggest that teacher beliefs guide to a substantial extent how much teachers value different aspects of knowledge and how much emphasize different content (Cheung & Wong, 2010; Cronin-Jones, 1991; Haney, Czerniak, & Lumpe, 1996). Teachers' 'personal knowledge' is not static, but is formed through everyday experiences and formal schooling, including teacher education, and continues to be molded in continuing professional education (Gess-Newsome & Lederman, 1995; Henze, Van Driel, & Verloop, 2007; Van Driel, Beijaard, & Verloop, 2001), and this personal knowledge shapes teaching to a large extent (Hashweh, 1987, 2005; van Driel, Bulte, & Verloop, 2008). Nevertheless, personal knowledge often manifests through rules-of-thumb, rather than formal design (Wieringa, Janssen, & van Driel, 2011). Consequently, curricular change can cause very little change in teachers' behavior if underlying beliefs about content and the best suited methods to teach content are not changed (Cohen & Yarden, 2009; Tidemand & Nielsen, 2017).

The main tools for content selection are the available teaching materials, especially textbooks (Remillard & Bryans, 2004; Shawer, 2017; Spiegel & Wright, 1984). Among teachers, there is a conflict between following the textbook's content and using them critically, as teachers seem to understand critical reading of texts as distancing themselves from the text (Ball &

Feiman-Nemser, 1988). Teachers cite regularly understanding of the content as an important aspect: the more they perceive to have confidence in their own capabilities to deal with course content and to adapt it to classroom context, the more they can depart from the teaching materials and make more unconventional choices in implementing curriculum (Davis, Janssen, & Van Driel, 2016; Nicol & Crespo, 2006).

In general, teachers are poorly prepared for teaching controversial issues (Oulton, Dillon, & Grace, 2004; Oulton, Day, Dillon, & Grace, 2004) and especially less experienced teachers do not seem to select topics that could be upsetting to students (Hess, 2008; Phillips, 1997). Arguably teacher beliefs are important factors in whether teachers embark on discussions of controversial issues (Cotton, 2006)). While controversial or sensitive issues have been largely studied in history and social science (i.e., Oulton, Dillon, & Grace, 2004; Oulton, Day, Dillon, & Grace, 2004; Hess, 2008), science subjects, and especially biology, do not lack controversial topics (Leonard, 2010; Levin & Lindbeck, 1979; Owens, Sadler, & Zeidler, 2017).

Nevertheless, science teachers seem to be hesitant to adopt societally-relevant teaching methods (Day & Bryce, 2011; Sadler, 2011). For example, in discussing controversial issues, teachers have mentioned common previously formulated problems in beginning and maintaining discussions, dealing with students' "lack of knowledge", insufficient teaching time, and scarcity of resources (Dawson & Venville, 2008; Dawson & Taylor, 2000; Hand & Levinson, 2012; Kuş, 2015; Reiss, 1999). It seems that the knowledge of context-dependent teaching, student-centered teaching, or teaching the Nature of Science is not enough for these themes to manifest in teaching practice (Bartos & Lederman, 2014; Mansour, 2013). One of the solutions should be increasing teachers' confidence to implement teaching societally-relevant issues, even though they could be controversial (Hofstein, Eilks, & Bybee, 2011).

Genetics education and socio-scientific issues

It has been argued that socio-scientific issues lie at the very core of genetics education; thus, a substantial amount of research in genetics education has been dedicated to studying and discussing how societal issues can be tackled in genetics education (Sadler & Zeidler, 2004). The central issues include, but are not limited to, genetically modified organisms, cloning, gene editing, stem cell research, genetic disorder testing, and risk assessments through genetic testing (Boerwinkel, Yarden, & Waarlo, 2017; Lederman et al., 2014; Shea, Duncan, & Stephenson, 2014; Siani & Ben-Zvi Assaraf, 2016). These issues have also been included in many national or local curricula (Stern & Kampourakis, 2017), but in general, similar problems seem to hinder teaching socio-scientific issues in genetics as in other sciences (Lederman et al., 2014).

Genetics education has been emphasized in recent years, as the progress in both basic science of genetics and the technological applications has been rapid. This leads to both quickly evolving genetics curricula, and the constant requirement of teacher development in conceptual, procedural and pedagogical knowledge. Thus, biology teachers should be knowledgeable not only in genetics, but also modern technologies based on genetics, and they should be able to discuss their implications. Albe and Simonneaux (2002) used a theory of planned behavior (Ajzen, 1991) to approach this problem and they revealed stark differences between different subjects and how teachers' attitudes towards SSI are shaped. The question of identity of the teachers, as experts in biology versus experts in discussing human genetics seems to be one of the central problems (Pedretti, Bencze, Hewitt, Romkey, & Jivraj, 2008; Tidemand & Nielsen, 2017). This seems to also be reflected in the students: for example, in a Swedish study, upper-secondary school students majoring in science used few justifications from ethics or morality when discussing GMOs (Christenson, Chang Rundgren, & Zeidler, 2014).

Genetics in the Finnish upper-secondary school curriculum

Finnish curricula tend to leave substantial freedom for teachers to interpret the educational aims and develop multiple different methods to implement curricula. Finnish teachers plan teaching according to local curricula, which are formulated by the education providers and schools based on the national core curriculum for general upper-secondary schools (Finnish National Board of Education, 2004). The core content pertaining to genetics is mostly limited to two courses: Cells and heredity (BI2), which is mandatory, and Biotechnology (BI5), which is an optional course. The only directly SSI-related topics mentioned among biology core content are ethical and legal issues of genetically modified organisms (GMOs). The general part of the national core curriculum mentions cross-curricular themes, including active citizenship, and technology and society, that should be "taken into account in instruction in all subjects as appropriate for each particular subject." Thus, teachers have substantial freedom to choose both content and teaching methods.

Finnish secondary school science teachers' education is organized in co-operation with two faculties, so that the major subject is studied at a faculty of science, and minor pedagogical studies emphasizing biology subject education is organized by the faculty of education (Lavonen & Juuti, 2012). Thus, biology teachers can have a master's level degree in one school subject, and minor studies in other school subjects and even in educational sciences. Usually biology teachers have studied either biology or geography as their major subject in the university.

We were interested in how teachers describe their teaching practices and course content in an upper-secondary genetics course. As the Finnish school framework provides for ample freedom for teachers to adopt the most suitable teaching methods and biology teachers are generally educated broadly in different fields of biology, this allows for exploring the links between genetics content, SSI, and teacher perceptions of genetics as a scientific field. We used interviews to better understand what content and concepts the teachers thought were the most important for the students to learn, within the context of the Finnish upper-secondary school core curriculum, but also inquired about the societal relevance of genetics and how teachers approach sensitive subjects.

Methods

Our research design was qualitative case study. We conducted open-ended semi-structured interviews with 10 upper secondary high school biology teachers from various schools from Southern and Western Finland between 2015 and 2016 (Table 1). Teachers were selected purposively to reflect a variation in experience, gender, type of school and geographical location in order to access many different teachers with knowledge about upper secondary school gene education. All teachers had biology as a major subject in their university master's degree. Some teachers taught partly in schools that have specialized in certain subjects or in schools that use other another curriculum rather than the Finnish national core curriculum.

Teachers were asked: a) how they teach genetics, b) how they acquire knowledge and c) what examples they use during the two courses, BI2, for Cells and heredity course for all students, and BI5, a Biotechnology optional course (Table 2). Especially, we asked how teachers teach the topic of GMOs in the BI5 course and what kind of examples of human genetics they use in courses BI2 and BI5. The first topic, GMOs, is explicitly mentioned in the national core curriculum, and teachers must teach students to understand the ethics of GMOs. The second topic, hereditary disorders, is not mentioned in the national curriculum, but practically all usable human examples of Mendelian genetic traits are hereditary disorders. Thirdly, complex human traits, like intelligence, are not mentioned in the curriculum, but the topic can be raised while discussing polygenic inheritance. These topics are along a continuum of how easy it is for teachers to avoid discussing them. All three content areas can be argued to be central parts of different SSI, such as food production and consumption, personalized medicine, and the effect of genetics in human individual differences.

During the interviews, we observed that teachers have differing attitudes towards specific content, examples and SSI. We decided to recursively analyze the data (Strauss & Corbin, 1990). While the framework of the larger research project limited theoretical sampling, so we had to use the sample of ten teachers, but that still allowed for the refinement of the interview questions during the study.

We analyzed the data in a six-stage process: 1) we transcribed the interviews; 2) we coded the transcripts one sample at a time by: a) which subject matter teachers thought was the most crucial and which could be left aside, b) how they argued for including or excluding certain course content and c) how they described what they feel students feel important; 3) beginning from the first sample, we named concepts arising from the grouped codes and after each sample, recursively performed stages 2 and 3 for previously-coded samples (which would correspond to initial analysis as per Charmaz (2003); 4) after initial samples were coded and concepts named, we integrated categories (focused analysis); 5) we contrasted the teachers to each other to understand the connections between categories, and 6) we refined the theory. We used the R (R Core Team, 2013) package RQDA (Huang, 2017) for the analysis.

Transferability was improved by a rich description of the research process in the form of an audit trail. A second author evaluated the dependability and confirmability of the study by examining the audit trail for original analysis. The audit trail was refined and complemented and also the resulting theory refined during the process of audit trail evaluation.

Findings

Interview and coding process

The interviews lasted from 40 minutes to 1 hour and 32 minutes. The length of the units of analysis varied from a single description of gene structure or function, which could be only few words, to long, continuous, uninterrupted monologues. Open coding in the beginning was extensive as it consisted of all mentions and descriptions of genes as they are taught in either the BI2 course or the BI5 course and how these differ from actual scientific models of genes.

We coded all the examples teachers mentioned they use to describe gene function, what they describe as the most central content in teaching genetics, and what they called the common problems in learning genetics. We also coded every instance of teachers' arguements for the relevance of genetics education. When coding SSI, controversial and sensitive issues, three different content groups emerged: monohybrid crosses in humans, polygenic properties of humans and GMOs. Within these three groups, we coded all the mentions of the issues the teachers described that a) they use in teaching, b) they avoid using in teaching, c) the topics in which the students express interest, and d) topics in which the students express no interest in. We then advanced to axial coding by simplifying authentic expressions in the open codes to a combinations which would describe general-level biological phenomena. After half of the samples were coded axially, selective coding was used to delimit the coding process.

What do teachers see as the most important content in genetics courses?

When we asked teachers to summarize what they hoped students would learn from upper-secondary school genetics courses, they described different content. We divided these to three distinct themes: 1) development of phenotype, 2) inheritance and continuity and 3) the function of the genes.

The first theme, development of phenotype, contains descriptions that focused on understanding how genes and environment shape the development of different traits (i.e., genetic determinism). These descriptions were often related directly to how students themselves have developed an understanding of how human individuals have formed:

> Teacher J: "Humans are constructed by many factors, of which genome influences greatly, or they are things which we cannot influence ourselves; they come directly from the genome, but also genes do not dictate how we live our lives, what kind of persons we are, and how we behave."

The second theme, inheritance and continuity, is centered on the concept that there is genetic continuity in the tree of life and that DNA copies itself from generation to generation. Teachers who described concepts relating to this theme saw the understanding of evolution as the focal point of whole field of biology and saw genetics as central to this understanding. Biodiversity was mentioned as one manifestation of this continuity. Sometimes the descriptions of the most important ideas were almost affective:

> Teacher C: "The common thread of life, from the beginning, the same genes are flowing; we are composed of genes from a million persons from thousands of years and then a new combination pops up, from the stream of life."

The third theme, the function of the genes, was the simplest theme in terms of how teachers described it. They usually said that it was important to understand what genes are and how they function, while offering no reference to any reason why it is so. Some teachers mentioned that it is important in terms of general knowledge to know these topics.

> Teacher B: "If I say it concisely, what is the gene and how does it function is the core knowledge a student should have."

Some teachers gave several descriptions that fitted two of these themes, but none described all three. While several teachers mentioned that it is important that students know how to analyze SSI related to genetics and biotechnology, they never mentioned such analysis in the context of the most important content of the course. Rather, teachers explained how understanding biological content could help students to understand SSI:

> Teacher A: “One has to understand something about genetics, so you can participate in a discussion about genetic modification, or, think about what it means in your own life, but this is rather small part at the beginning of the course to motivate students.”

While no teachers mentioned that any core content should be dropped from the courses, several teachers criticized the level of detail in the coursework. The only criticism mentioned by multiple teachers was the excessive emphasis on exercises counting probabilities and analyzing pedigrees of Mendelian traits. In contrast, some teachers mentioned that students who are not necessarily interested in the details of cellular functions appreciate these exercises and feel rewarded when they successful complete the exercises.

GMOs

Most of the teachers approached ethical questions as being superimposed on the biological content within a course and they thought the students should know the biological contents before discussing GMOs. Some teachers also suggested that students have highly polarized opinions before coming to a course and that “knowledge” could help in seeing the different aspects of the debate.

> Teacher F: “We have two types of students, so that they are pretty black-and-white. Some of them have already been kind of brainwashed to think that “this is all great”, while a minority, or I don’t know if they don’t just dare to tell me, are against GMOs.”

Three teachers said that they use SSI as a means to motivate students in the beginning of the course, while the other seven said that they first teach the biological content and then move to ethical discussions. Still, ethical questions were seen as secondary to biological content:

> Teacher J: "…there's not always much time for discussions – the time spent in ethical discussions is always reduced from less than what is spent on the course texts."

Teachers were divided on the question of students' interest in the ethical aspects of genetics. Some felt that these issues are not relevant for them as "the students don't do grocery shopping," whereas other felt that students were in general interested in SSI. Some mentioned their own role in motivating students and acknowledged that teachers could awaken their interest with certain examples, or anecdotes. Teacher I noted "It [students' motivation] depends on how thrilling the examples I use are!"

The atmosphere of school or the general attitude of students was often invoked as an explanation of students' interest or lack of interest in GMOs; certain teachers, especially from upper-secondary schools with national specialization, described their students as being more interested in societal issues or natural sciences than in general, while some teachers described their students as not interested at all. Some teachers also admitted that they are not very good at encouraging discussion.

Human genetics

Teachers mentioned that the use of human examples in genetics is mostly limited to Mendelian disorders in BI2 course and more complex traits are then discussed at the end of BI2 or during the BI5 courses. Teachers said that they do not use many examples of human traits were because they lack good examples, they try not to focus solely on humans, but on all organisms, and that they feel some issues involving human genetics are sensitive.

Teachers commonly held the opinion that students are interested in hereditary phenomena in general, but there is mismatch in how textbooks frames genetics and what the students' interests are: while students are mainly interested in human genetics, the textbooks lack good examples and teachers did not feel themselves competent to go deeper into the topic:

> Teacher J: "… [student asks] if I have blue eyes and my boyfriend has brown eyes, then what color will our children's eyes be, but unfortunately I have to try to contain their excitement as I don't know the answers to their questions."

Teachers acknowledged that one problem in the textbooks is that most of the Mendelian traits used as examples concerned hereditary diseases, which might give students a distorted image of the breadth of issues that genes cover. Some teachers mentioned that they use classic, if not the most correct, examples like a widow's peak or rolling the tongue. All teachers who used these examples said that, nevertheless, they mention to students that in reality, genetics is not that simple. Teachers often mentioned that they need to consider both students' previous knowledge and their motivation. The optional BI5 course was seen as giving a much more "realistic" picture of genetics than the mandatory BI2 course:

> Teacher H: "I begin the course [BI5] by saying to the students that they should forget everything they have previously learned about genetics."

Two teachers mentioned that they try to avoid talking about humans in general and three other teachers said that they try to avoid discussing complex human traits, such as talent, intelligence, or human behavior:

> Interviewer: Do you discuss how genetics affects learning? What if some students have genes that allow them to achieve better grades?
>
> Teacher E: No, no. (pause). No.
>
> Interviewer: No?
>
> Teacher E: No, we don't discuss that.
>
> Interview: No one is interested?
>
> Teacher E: No. I'm not interested either (laughs)

> *Interviewer laughs*
>
> Teacher E: I think it is very sensitive issue. I would reconsider several times before talking about it.

Most teachers said that they discuss human behavioral genetics if students ask questions, but they do not bring the topic up themselves. The two teachers who avoid humans as a topic argued that humans are just one species, and it is not sensible to concentrate too much on humans in biology. In contrast, some teachers said the discussions are needed, especially in the context of racial issues:

> Teacher D: "It is relevant for the students if it is discussed in public, societal debate – [they may want to know if] citizens from certain continents are less intelligent than others–, and we have discussed these alternative news a lot, how they publish utter nonsense."

Many teachers mentioned or implied that complex human traits are inherently so complex that they subject is are not fruitful to teach: there is a risk that students would form misconceptions on overtly genetic determinations of these traits. Furthermore, the lack of examples and lack of teacher competence was seen as leading to teaching without sensible content:

> Teacher A: "…but I don't know anything about how genes affect learning abilities[laughs] So, the discussion normally concludes with my comment that 'it's a complex issue'."

Many teachers acknowledged that discussing human heredity can pose several challenges. For example, using blood group testing can raise questions and even distress students if their blood group is not concordant with their parents' blood groups. One teacher mentioned she does not want to do pedigrees on simple traits with students because of the "diversity of families" and her not knowing the backgrounds of the students. Furthermore, some teachers avoid complex traits, like human intelligence, mentioning that it is sensitive issue.

Human genetic disorders are special cases of sensitive issues as some student groups possibly contain students that have genetic disorders or who have someone in their family or among friends who is affected. Teachers diverged on how willing they were to discuss those. Those teachers willing to discuss genetic disorders of students or their families argued that generally those affected know best about the issues. One teacher also mentioned that sensitive issues bring up emotions, but that it is also natural in a classroom setting:

> Teacher C: "Sometimes I've gone and hugged a student – I find it a good way to calm down. – Every now and then I have tears in my eyes, but I think it's important to show my own persona in my teaching."

Teachers frame genetics teaching with different approaches

Teachers' perceptions of the most important genetic content were closely related to their willingness to teach different topics or even what they said that students find interesting. For example, none of the teachers whose theme in genetics teaching was classified as "development of phenotype" mentioned that they try to avoid human complex traits. In turn, both teachers who said that students are interested in gene testing had their theme grouped to "inheritance" and both teachers who mentioned students are interested in epigenetics to "development of phenotype."

Three different general approaches of teaching genes and their role arose from the analysis: *Developmental*, *Structural* and *Hereditary* (Table 3). A *Developmental* approach frames the development of traits as the central theme in genetics and consequently teachers who used this approach were largely open to any discussions, they did not mention any topic they would avoid, and most of them mentioned that they have regular discussions about complex human traits as they felt that students are most interested in these. These teachers were all comparatively the less experienced teachers of the interviewed group (12 or fewer years of experience). Their approach contrasts with two teachers who used a *Structural* approach mentioning only gene function as the central issue. These teachers mentioned avoiding discussing complex traits in humans or humans at all, as they find these both sensitive and not good examples of polygenic inheritance. In contrast, these teachers described hereditary analysis as an interesting part of the genetics course. They were among the most experienced teachers (> 20 years). A third approach, *Hereditary*, was characterized by emphasis on the continuity of DNA through the whole tree of life. This context manifested in teachers' answers as being somewhere between the two previous approaches. Teachers which used this approach were willing to discuss complex human traits if the students asked about them, but did not actively raise examples. They generally used an example of human skin color as an example of polygenic traits. More broadly, in genetics, they usually emphasized the understanding of phenomena related to DNA duplications, such as meiosis. A hereditary approach was used by both less and more experienced teachers.

In contrast to the issues involving the human complex traits, the gene teaching approaches were not connected how teachers taught GMOs. While some teachers were more dismissive about teaching on SSI while discussing GMOs, and said that there was not always time to go through those topics, they were not differentiated based on their genetics approaches. Furthermore, one teacher who said that they use GMOs as a motivation in the beginning of the course, to explain how genetics are important, said that they do not always have time to go into ethics of GMOs. In general, lack of time is a general perception of teachers in different subjects and countries (Adams & Krockover, 1997; Archbald & Porter, 1994; Fuller, 1969) and the interviewed teachers also expressed this idea repeatedly. This reason worked in concert with the acknowledgement from most teachers that their teaching closely follows to the textbook, and textbooks tend to discuss SSI at the end of the book (Aivelo & Uitto, 2015).

The tentative model on factors influencing choosing course content

While the majority of the teachers interviewed said that they follow closely the textbook content, they still described their teaching in very different terms. While the content choice of biology textbooks for upper-secondary school is highly similar (Aivelo & Uitto, 2015), teachers clearly had different contexts of understanding genetics. All schools follow the national core curricula, and this was evident in teachers' descriptions of their choices. Furthermore, this was emphasized by the inclusion of SSI related topics to the study of GMOs in the biology core curriculum and that subsequently all teachers mentioned taking this as a part of their BI5 course independent of their genetics teaching approaches. The National Core Curriculum is also the basis for the questions on the matriculation examination and teachers acknowledged that previous exam questions guide their teaching.

The aforementioned factors are more or less similar for each teacher, but our results also reveal perceived differences among teachers and the context in which they are working. Some of the teachers compared their school to other schools, and suggested that some attributes of their school attract certain kinds of students. Likewise, teachers described differences in course arrangements, and noted if it was possible to do experiments in classroom. Teachers also described many internal influences on what they teach. On many occasions they acknowledged the limits of their competence, either regarding genetics, such as when they are unable to answer complicated student questions, or pedagogically, when they mentioned they might have problems in successfully guiding classroom discussions. Nevertheless, the aforementioned approaches were an important explanation of how teachers describe their teaching.

Based on these interviews, we formulated a descriptive tentative model on how teachers choose content for their courses (Fig. 1). While the National Core Curriculum is evidently guiding teachers' descriptions of their teaching, they mentioned that it mainly directs their teaching mainly due to teaching materials, and due to matriculation examination questions. Teachers also mentioned several local issues guiding what they can teach, mainly local school preferences as some schools either have traditions or emphasis on biology or sciences. This can be seen in the number of biology courses taught, to what extent students are interested in biology, and how much has been invested in school infrastructure such as laboratories for classes. Furthermore, teachers expressed personal factors, including how much they feel they know about genetics, or their teaching skills as teachers are. Nevertheless, the teaching approach also affects what teachers assume their students are interested in.

Trustworthiness of the study

We continuously evaluated the trustworthiness for our study in several ways (Brown et al., 2002; Morrow, 2005). Credibility was ensured by the chosen research procedure. For instance, we engaged with the participants throughout the school year: while the interview took place only once, the teachers gave questionnaires about our research project to their students whenever they had a genetics course to teach. During the category formation, we looked for disconfirming data and assessed data saturation. The interviews were modified and refined throughout the entire process; they were conducted in the same order as they were analyzed.

The initial open coding was rich and diverse, leading to the finding of the first-order and second-order categories. All through the coding and category formation, we looked for disconfirming data and assessed data saturation (Saunders et al., 2017). The credibility was enhanced by continuous discussion and revising the meanings and coding of the data during the categorization by the first author and the transcriber, who was a sociolinguist. Purposive sampling fitted well this research approach as our data was rather rapidly saturated: by the ninth and tenth sample, there was no new information useful for the category formation. There were variations in how teachers described the central themes of their genetics courses.

While some used elaborate metaphors (e.g., genes are "*complex blueprints for humans*," Teacher J), the others just described a single topic (e.g., "*cell function*," Teacher E). Nevertheless, we assume that these differences in describing larger processes versus singular topics are a feature of teaching approaches.

To ensure the conformability of the study, after the meaning-making analysis, the second author took the role of the inquiry auditor (Brown et al. 2002) and audited the whole process. Both the audit trail and resulting putative theoretical models were refined, based on the authors' discussions and revisions.

While we do not suggest, that the results are readily generalizable for other science teachers, some suggestions for the transferability can be made. One reason for the rapid saturation may be the similarities in the educational background of the teachers, as all had master's degree with biology as the major subject, and pedagogical studies in teacher education as a minor subject. Moreover, the text books the teachers use are quite similar, emphasizing gene structure and function (Aivelo & Uitto, 2015). However, curriculum for upper-secondary schools gives a substantial freedom to teachers to interpret the contents and goals of biology education in classroom practice (FNBE, 2003). This may partly explain the fundamental differences in teaching approaches that we found. Thus, we suggest that the putative content-choosing model provides a well-grounded hypothesis for further research on the teaching approaches of experienced, autonomous biology teachers. The relationship between teaching approach and the choice of course content could provide a more widely applicable hypothesis for science teachers, who have freedom to choose whether or not to apply SSI-based approaches to their courses.

Discussion

Teachers' perceptions on genetics teaching reflects their choice of course content

Our findings suggest that there were fundamental differences in Finnish upper-secondary school biology teachers' perceptions on the most important themes in genetics and genetics teaching and subsequently how they chose course content while teaching genetics. Their perceptions are reflected in the issues that they bring up in genetics courses and what contents and examples they find important. Teachers' perceptions on genetics teaching are formulated on the basis of what teachers interpret as the central issues in genetics, how they conceive their competence to teach it, how they understand students' attitudes towards different issues, and what they expect students would learn. Furthermore, their perceptions are connected to what they say students think are interesting topics. As a part of our larger research project, the students of our research schools filled out questionnaires that explicitly asked which topics they find interesting. Thus, we will be able to later discover how precise perceptions teachers actually have of their students' interests.

While we have limited knowledge on the background of our interviewees, the teaching experience in years emerged appeared to be a plausible reason to the different approaches of genetics teaching (Table 3). Contrary to the results of previous studies (Hess, 2008; Phillips, 1997), our study showed that Finnish teachers were more open to discuss complex human traits and other sensitive issues in classroom if they were less experienced. All our interviewees had been teachers for almost all of their working career, thus, the experience related clearly with both their age and the period during which they studied biology at the university. This means that the formation of a genetics teaching approach may also depend on the past university course content of genetics, and the pedagogical studies the teacher has completed. As mentioned, we were not able to differentiate which of these factors–if any–underlie the formation of their approaches to genetics teaching. It would be interesting to further study how teachers' experience and university training shape the teaching approaches.

Our model can be also examined in the context of pedagogical content knowledge (PCK) models (Grossmann, 1990). Genetics teaching approaches can be seen as partly overlapping with "science teaching orientations" (Magnusson, Krajcik, & Borko, 1999) as they contain knowledge of the importance of different concepts, interpretation of curricula, the motivations of the students, and representations and context of core concepts. In comparison, while orientations describe the whole approach to teachings and especially instruction methods, approaches rarely limit the instruction methods. Nonetheless, the presence of different approaches raises the question of how differential teacher understanding of core concepts influences teaching methods or orientations to teaching science.

Our findings are similar to those of Van Driel et al. (2007), who found separate subgroups of teachers who teach either subject-matter oriented or learner-centered, but also large subgroups which combine these two approaches. Our results also agree with Tidemand and Nielsen's (2017) suggestion that emphasis on biological content (as opposed to more societal approaches) is driven by teachers' identity as biology teachers. Our results also show a strong preference for biological content in comparison to more societal topics.

Socio-scientific, sensitive and controversial issues

Our results are strongly relevant to SSI research. While SSI has been advocated as an important feature in science education, teachers have been slow to adopt it as part of their teaching practice (Lazarowitz & Bloch, 2005; Lee et al., 2006). While the same conclusions can be also drawn from our results, this is not only an issue of teaching methods: in many cases, teachers mentioned that they do not have enough content knowledge. Similarly, the teachers who avoided sensitive issues use the complexity of the contents as an argument. Our interviews showed a paradoxical approach by teachers: while they said that genetics is a societally relevant topic, and that students should learn analytical tools to take part in decision-making and be responsible consumers, this was not evident in their descriptions of their teaching. Without exception, teachers formulated the basic science as the main issue and, in many cases, SSI was described to be taught only “if there was time at the end of the course.” Content knowledge is important for successful reasoning regarding SSI: thus, a delicate balance needs to be sought (Lederman et al., 2014; Sadler & Zeidler, 2004). Still, the emphasis on biological content – the lack of which is even cited as a reason why SSI are not more widely discussed - echoes the previous results that show the primacy biology teachers give to biological content (Tidemand & Nielsen, 2017). Nevertheless, it can be argued that from the point of view of SSI, there is never *enough* scientific evidence to determine decisions; thus, biological contents should not have priority over SSI (Nielsen, 2013).

Teachers rarely mentioned why they would actually avoid sensitive issues, though some teachers explicitly mentioned that they felt they were competent in handling the affective part of sensitive issues. Thus, we are not able to suggest whether avoidance of sensitive issues would be due to teachers thinking discussion on sensitive issues would lead to non-beneficial learning outcomes because of student reactions or rather that teachers themselves do not feel competent or comfortable in placing themselves in sensitive situations.

We argue that not all sensitive issues in genetics teaching are socio-scientific issues. Teachers often framed problems in discussing human genetics on personal rather than a societal level. That is, teachers said that they did not know how to handle students’ personal reactions arising from discussing genetic disorders, and they would rather keep distance from such personal relevance. Thus, the personal relevance of genetics can be a double-edged sword in the classroom. This needs to be addressed more in professional development. In general, the ways of teaching controversial issues are not well-studied and the recommendations themselves are controversial (Oulton et al., 2004).

We suggest that it might be useful to distinguish between controversial, socio-scientific and sensitive issues (Fig. 2). Our schema for this differentiation works along the axis from personal to less personal or societal. We define socio-scientific issues as controversial social issues relating to science (Zeidler & Keefer, 2003). Nevertheless, there are also controversial issues that are not socio-scientific, such as understanding of evolution or other non-societally-relevant debates. Then again, controversial issues might not be sensitive, if students do not have a personal stake in the debate. In turn, while many issues such as genetic disorders, could feel very personal for students and they could be sensitive issues, they might not be controversial. Whether an issue is societally controversial or personally sensitive, it could require that teachers use very different approaches. In relation to genetics, most teachers that we have interviewed were more worried about the personal sensitivities rather than societal controversy.

Implications for teaching practice

In school practice, the teachers should be made more aware and provide opportunities for self-reflection more on the approaches they take in teaching science. Gene and gene concept have been widely studied as an example of a concept with multiple representations, and these representations can clearly be identified in the descriptions that the teachers gave in interviews (Tsui et al., 2013).

In light of GMO SSIs being integrated in the teaching, independent of teacher inclinations, we suggest that the curriculum development would be sensible approach if genetics education aims to better incorporate societal relevance. SSI should be more intimately incorporated to other contents in the biology curriculum. Furthermore, curriculum development needs to be connected with teacher education emphasizing pedagogical content knowledge (Käpylä, Heikkinen, & Asunta, 2009). While teachers appreciate a “knowledge first” approach to SSI issues, there is a perceived lack of useful and tested teaching materials and teachers would need training on how to avoid the pitfalls of false equivalence or indetermination when teaching complex issues. Thus, SSI should be taken more into account in science and especially in biology teacher education and in-service training. Indeed, the renewed Finnish curriculum for upper-secondary schools (FNBE 2015), which was implemented after our data collection emphasizes teaching SSI. Consequently, if the curriculum strongly directs how much SSI are discussed in the Finnish classroom, if we were to replicate our study now, we should find that teachers emphasize SSI more. If the teachers have not changed how often they approach SSI in teaching that would be indicative of lesser influence from the national curricula.

Conclusions

Based on qualitative case study and teacher interviews, we have built a tentative model of how upper-secondary school teachers choose which genetics content they generally emphasize. We found that, in general, teachers explained their choices with curriculum, teaching materials, and personal factors including university-level studies in genetics and teacher education, self-perceived skills in genetics and genetics teaching and assumed student knowledge and interest in learning genetics phenomena.

Teachers' perceptions on genetics teaching reflected three different approaches, emphasizing structural, hereditary, or developmental views in genetics teaching. These approaches include teachers' perceptions of the most important themes in genetic content, willingness to teach about human traits, and students' perceived interests. Teacher experience was related to their approaches, so that a developmental approach with a willingness to teach SSI occurred in the less experienced teachers, while more experienced teachers commonly had structural approach, which could even consist of avoidance of discussing SSI or sensitive issues. As we did not observe the teaching practice, we do not know how well these approaches manifest in teaching itself and whether these have an actual effect on student learning outcomes. Our ongoing research project could shed light in this by comparing student interests and attitudes to teacher genetics teaching approaches.

Our results revealed different approaches to genetics teaching, which led to an emphasis on different content and understanding of gene concepts and an avoidance of certain topics, such as discussing societally relevant issues. These approaches were related with teacher experience as more experienced teachers were less likely to discuss sensitive or controversial issues.

Our results suggest that either teacher experience or the period when they studied genetics correlates strongly with how they perceive what the core content of genetics is. We also argue that curricular development is an effective way to increase the prominence of SSI in biology education.

Acknowledgments

The authors wish to thank the ten biology teachers who participated in this study, Marlene Broemer for checking the language in manuscript, Lotta Aarikka for transcribing the interviews and providing debriefing during initial analysis and Justus Mutanen for fruitful discussions.

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Table 1: Ten female and male teachers that were included in the study. The upper secondary schools are divided by type: General: national curriculum; Adult education: similar to national curriculum but fewer obligatory courses, SP: specialized school that have a core curriculum similar to the national curriculum but fewer obligatory courses, and OC: uses another curriculum than the Finnish national core curriculum

Teacher	Years as teacher	Gender	Region	Upper secondary school
A	3	Female	Helsinki	Adult education
B	12	Male	Helsinki	General/SP
C	27	Female	Western Finland	General/SP
D	7	Male	Helsinki	General
E	26	Male	Western Finland	SP
F	11	Female	Helsinki	General/OC
G	20	Female	Helsinki	General/OC
H	8	Female	Western Finland	General
I	9	Male	Helsinki	General
J	6	Female	Helsinki	General

Table 2: The Core content described in the Finnish national curriculum with selected parts from courses BI2 and BI5

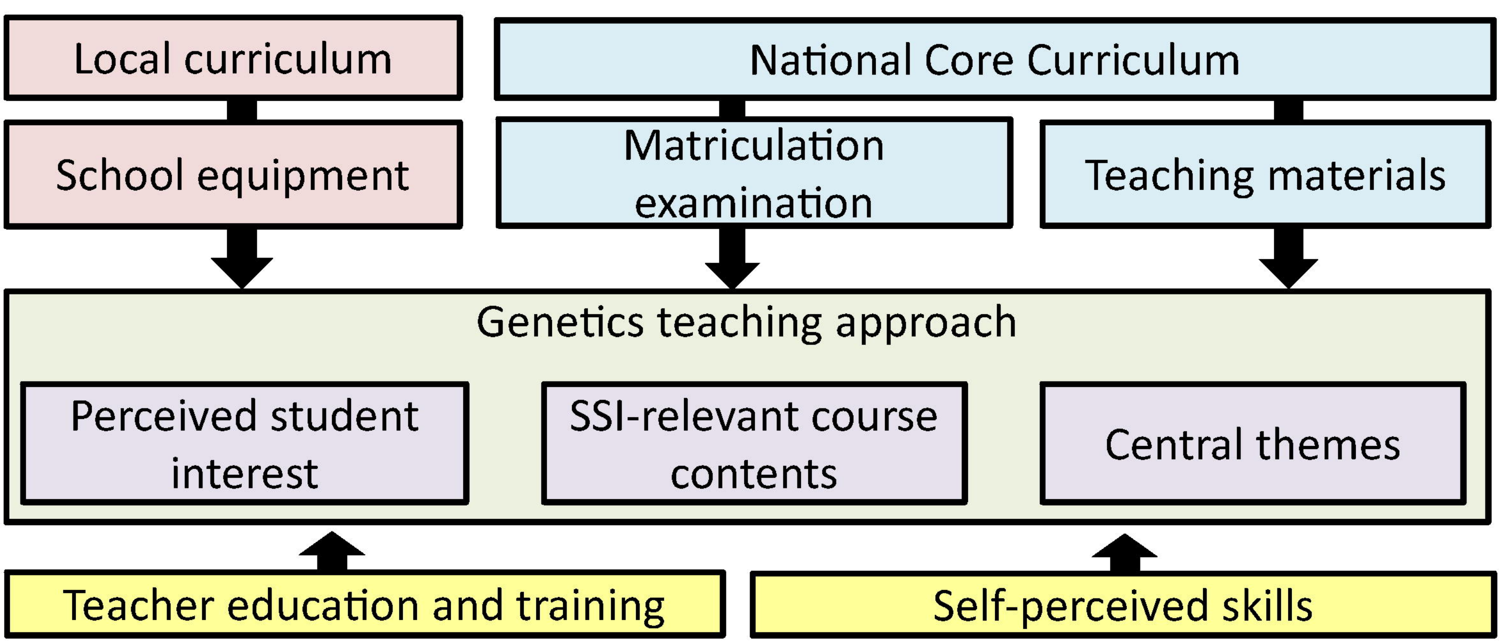
Topics	BI2—Cell and genetics	BI5—Biotechnology
DNA and genes	DNA structure and function	DNA, gene and genome structure
	Genes and alleles	
	Protein synthesis	Gene function and regulation
Cell functions	Gametes and meiosis	
	Mitosis	
Inheritance	Inheritance mechanisms	
	Population genetics	
Applications		Gene technology
SSI		Ethics and legal issues in gene technology

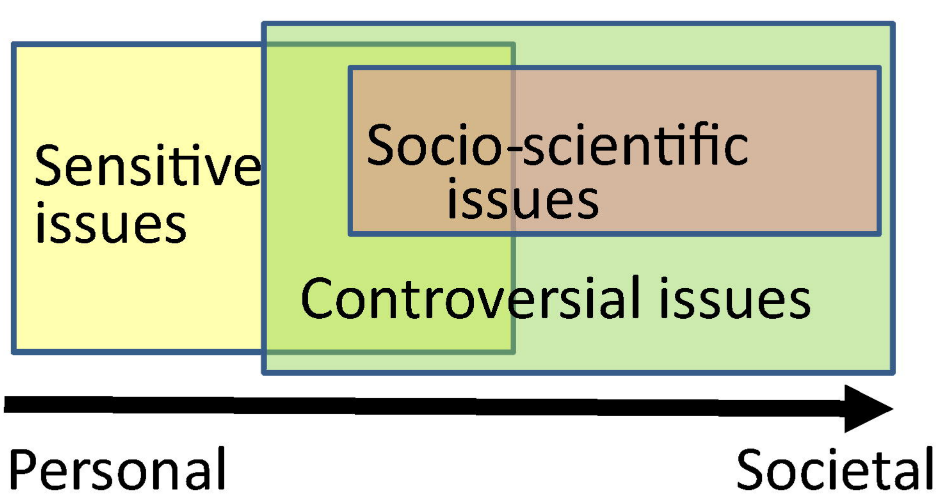
Table 3: Categorization of teachers' perceptions on central themes in genetics teaching, willingness to teach on human traits, perceived students' interests and the teaching experience in years

Approach	**Structural**	**Hereditary**	**Developmental**
Central theme	Gene structure and function	Continuity of DNA through time	Development of traits
Human Mendelian disorders	Avoid	Use as examples	Use as examples
Complex human traits	Avoid	If students ask	Use as examples
Perceived student interest	Monohybrid, dihybrid crosses	Gene tests, medical genetics	Epigenetics, complex human traits
Teacher experience	>20 years	Wide range	12 or fewer years

Figure 1: Tentative model of factors relating to teachers' emphasis on different genetics teaching approaches. The model is composed of three main groups: national core curriculum, teaching, and assessment materials made based on curriculum (blue), school environment including local curriculum and physical infrastructure (red) and personal factors (yellow). The genetics teaching approach (green) has three components, perceived student interest, SSI-relevant contents and central theme of genetics (violet) (See Table 3). The arrows visualize connections between items: the National Core Curriculum influences matriculation examination questions and teaching materials, which both influence course content. Teacher background and self-perception as a teacher in turn affect a teaching approach and local context also affects course contents

Figure 2: The suggested relationship between socioscientific, controversial and sensitive issues in science education


Local curriculum
National Core Curriculum
School equipment
Matriculation examination
Teaching materials
Genetics teaching approach
Perceived student interest
SSI-relevant course contents
Central themes
Teacher education and training
Self-perceived skills


Sensitive issues
Socio-scientific issues
Controversial issues
Personal
Societal