Teachers' approaches to genetics teaching mirror their choice of content and avoidance of sensitive issues

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Abstract

The skills required 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 increasingly emphasised in science curricula, teachers have low interest in adopting SSI in teaching. Little is known about how teachers choose content for their teaching, although this process translates curricula to teaching practice. We explored how teachers choose content and contexts for biology courses on cells, heredity, and biotechnology by interviewing ten Finnish upper-secondary school teachers. We studied how the teachers described teaching on genetically modified organisms, hereditary disorders, and human traits. Teachers' perceptions on genetics teaching were classified to *Developmental*, *Structural* and *Hereditary approaches*. The approaches were connected not only to the teachers' perceptions of the more important content, but also teacher inclinations towards teaching genetics in the human context and perceptions of students' interest in different topics. Teachers' justified their choices by national, local school, and teacher's personal-level factors. While teachers mentioned that SSI are important, they were never mentioned among the important contexts. Nevertheless, some teachers embraced teaching genetics in the human context while others avoided them. Teachers justified their avoidance for personal and pedagogical factors, such as their competence in dealing with these contexts. Experience played a part in the approach that teachers had, and contrary to the results of previous research, the less experienced teachers were more open to discussing human genetics. We conclude that curriculum development is important to encourage teachers to adopt more SSI-oriented teaching.

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

Introduction

Curriculum articulates learning goals in school and thus guides teaching. Nevertheless, in Finland, national and local curricula usually leave a large proportion of content selection to teachers who might have considerable freedom to interpret and implement the written curriculum (Finnish National Board of Education, FNBE, 2003). While curricular development and its effectiveness have been studied extensively, there has been less research on how teachers choose the contents of their teaching.

Teacher beliefs guide how teachers value various aspects of knowledge to a substantial extent and how much they emphasise the 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 it continues to be moulded in continuing professional education (Gess-Newsome & Lederman, 1995; Henze, Van Driel, & Verloop, 2007; Van Driel, Beijaard, & Verloop, 2001), and this personal knowledge is important in shaping teaching (Hashweh, 1987, 2005; van Driel, Bulte, & Verloop, 2008). Nevertheless, personal knowledge often manifests itself through rules-of-thumb, rather than formal design (Wieringa, Janssen, & van Driel, 2011). Consequently, curricular change can cause little change in teachers' behaviour 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 teaching materials, especially textbooks (Remillard & Bryans, 2004; Shawer, 2017; Spiegel & Wright, 1984). Among teachers, there is conflict between following a textbook's content and using them critically, as teachers seem to understand critical reading of texts as distancing themselves from the text (Loewenberg Ball, Feiman-Nemser, Ball, & Feiman-Nemser, 1988).

Real world applications of science commonly involve controversial issues, while in general, teachers are poorly prepared for teaching controversial issues (Chris Oulton, Dillon, & Grace, 2004; Christopher Oulton, Day, Dillon, & Grace, 2004) and less experienced teachers especially do not seem to select topics that could upset students (Hess, 2008; Phillips, 1997). Arguably, teacher beliefs are important factors in whether teachers embark on discussions about controversial issues (Cotton, 2006). Most of the research on teaching controversial or sensitive issues has largely been in history and social science classes (i.e., Hess, 2008; Chris Oulton et al., 2004; Christopher Oulton et al., 2004), and science subjects are less studied, even though they also have controversial topics (Leonard, 2010; Levin & Lindbeck, 1979; Owens, Sadler, & Zeidler, 2017). In discussing controversial issues, teachers have mentioned problems in beginning and maintaining discussions, dealing with students' "lack of knowledge", insufficient teaching time, and scarcity of resources (V. M. Dawson & Venville, 2008; V. Dawson & Taylor, 2000; Hand & Levinson, 2012; Kuş, 2015; Reiss, 1999). One of the solutions should be to increase teachers' confidence to implement the teaching of societally-relevant issues, even though they could be controversial (Hofstein, Eilks, & Bybee, 2011).

It has been suggested that socio-scientific issues (SSI) 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). Nevertheless, teachers have been resistant to adopting SSI in their teaching (Lazarowitz & Bloch, 2005; Lee, Abd-El-Khalick, & Choi, 2006). Several reasons have been put forward to explain this phenomenon, including limitations of the curriculum or assessment techniques, teachers' pedagogical competence and that teachers lack of support for the merit of SSI discussions as being pertinent to specific learning subjects (Bryce & Gray, 2004; Gray & Bryce, 2006; Lewis & Leach, 2006; Newton, Driver, & Osborne, 1999).

Genetics education and curricular development

It has been argued that SSI 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). In general, these issues have also been included in national or local curricula (Stern & Kampourakis, 2017), but the problems that seem to hinder teaching SSI in genetics are similar to those in the other sciences (Lederman et al., 2014).

Genetics education has been emphasised in recent years, as the progress in both the basic science of genetics and the technological applications have been rapid. This has leds both to quickly evolving genetics curricula, and the constant requirement for teacher development. Thus, biology teachers should be knowledgeable not only in genetics, but also in modern technologies based on genetics, and they should be able to discuss their implications. Albe and Simonneaux (2002) used a theory of planned behaviour (Ajzen, 1991) to approach this problem and they revealed stark differences among teachers in 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 also seems to 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 (genetically modified organisms) (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 (FNBE, 2003) 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 (Table 1).

While teachers' attitudes towards different teaching methods have been studied widely, there has been far less research on the contents chosen by theachers for their teaching and how they justify their choices in an upper-secondary school biology 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 various fields of biology, this allows for exploring the links between the genetics content chosen for teaching and teacher perceptions of genetics. We used interviews to increase our understanding of what content and contexts the teachers consider to be the most important for the students to learn, within the context of the Finnish upper-secondary school core curriculum. We also studied teachers' perceptions on the societal relevance of genetics and how teachers approach sensitive subjects. We examined teachers' answers to questions about how they use three contexts in their teaching: GMOs, human hereditary disorders and complex human traits, such as intelligence.

The first context, GMOs, is explicitly mentioned in the national core curriculum, and teachers must discuss the ethics of GMOs. The second context, hereditary disorders, is not mentioned in the curriculum, but most examples of Mendelian genetic traits in human context are hereditary disorders. Thirdly, complex human traits, like intelligence, are not mentioned in the curriculum, but this context can be used to discuss polygenic inheritance. Thus, these contexts differ in how easy it is to avoid using them: while avoiding GMOs is not possible for teachers, complex human traits can be easily avoided.

Our research questions were:

1. What genetics content do teachers consider essential in upper secondary school biology?

2. Which genetics content do teachers choose to teach?

3. Which contexts do teachers choose for different contents?

Methods

Our research design was based on qualitative case study. We conducted open-ended semi-structured interviews with 10 upper secondary high school biology teachers from schools from Southern and Western Finland between 2015 and 2016 (see Table 2). 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. Additionally, we collected diary data and other teaching materials from teachers how they teach genetics.

Interviews

The interviews lasted from 40 to 90 minutes. Teachers were asked: a) what they perceive the most important content and contexts in genetics to be, b) how they acquire knowledge for teaching 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 1). We particularly asked the teachers how they teach GMOs in the BI5 course and what examples of human genetics they use in the BI2 and BI5 courses.

Our aim was to find out how teachers justify their content and context choices in genetics teaching. We used a theory-guided content analysis to categorize the data in a six-stage process by following the ideas of abductive analysis laid out by Timmermans and Tavory (2012): 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 thought students feel to be 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 from each other to understand the connections between categories, and 6) we refined the model. We used the R (R Core Team, 2013) RQDA package (Huang, 2017) for the analysis.

We contrasted the emerging codes with the assumption that teachers' content and context choices are guided by national and local curriculum, teaching materials and teachers' personal knowledge. When coding content choices, three groups emerged: monohybrid crosses in humans, polygenic properties of humans and GMOs. Within these three groups, on later recursion, 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. We then simplified authentic expressions in the open codes to a combination which would describe general-level biological phenomena, such as evolution, inheritance or gene expression. After half of the samples were coded, selective coding was used to delimit the coding process. Purposive sampling fitted this research approach well as our data were rather rapidly saturated: by the ninth sample, there was no new information useful for category formation. After the analysis process, we asked teachers whether they agrees with our analysis of the emphasis of their teaching, between developmental, hereditary or structural approach.

Trustworthiness

To assess the connection between the descriptions that the teachers gave of their teaching during the interviews and their actual teaching, we asked the teachers to keep a diary of their teaching after the interviews. We suggested that the teachers should write down the topics and teaching methods for each lesson, and which textbook chapters and exercises were discussed and which topics the students asked questions about or for clarifications. Additionally, teachers who had ready-made lecture slides sent those to us. An outside observer and the first author classified the diaries and other materials based on previously formed classifications (Table 2), which allowed us to compare teachers' interviews and actual teaching.

We continuously evaluated the trustworthiness of our study in several ways (Morrow, 2005). During the category formation, we looked for disconfirming data and assessed data saturation. The credibility was also 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. Transferability was improved by a rich description of the research process in the form of an audit trail. An audit trail was drafted based on the memos and the coding schemes developed. The authors evaluated the audit trail and agreed with the research process.

Findings

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

When we asked teachers to summarise what they hoped students would learn from upper-secondary school biology courses, the teachers mentioned different contents (Table 2, Table S1). We divided these into three distinct themes: 1) development of phenotype, 2) inheritance and continuity, and 3) the structure and function of the genes. Some teachers gave several descriptions that fitted two of these themes, but none described all three.

The first theme, development of phenotype, contains descriptions that focus 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 have developed an understanding of how human individuals have formed:

> Teacher J: "Humans are constructed by many factors, of which genome has great influence, 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 people we are, and how we behave."

The second theme, inheritance and continuity, is centred around 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 being central to this understanding. Biodiversity was mentioned as one manifestation of this continuity. Sometimes the descriptions of the more important ideas were 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 the gene is and how it functions is the core knowledge a student should have."

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 of GMOs before discussing their ethical dimensions (Table S2). Some teachers also suggested that students have highly polarised opinions on GMOs before coming to a course and that "knowledge" could help in seeing the various 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 to motivate students at 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 being 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."

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 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.

Human context in genetics teaching

Teachers mentioned that the use of human examples in genetics is mostly limited to Mendelian disorders in the BI2 course (Table 2, Table S3) and more complex traits are then discussed at the end of BI2 or during the BI5 courses (Table 2, Table S4). Teachers commonly held the opinion that students are interested in hereditary phenomena in general (Table S5), but there is a 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 colour will our children's eyes be, but unfortunately I have to try to contain their excitement as I don't know the answer to their question."

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 genetics is not really that simple.

Avoiding sensitive issues in genetics teaching

Two teachers mentioned that they try to avoid the human context in general and three other teachers said that they try to avoid discussing complex human traits, such as talent, intelligence, or human behavior (Table 2, Table S6):

> 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 a very sensitive issue. I would reconsider several times before talking about it.

Most teachers said that they discuss human behavioural genetics if students ask questions, but they do not bring the topic up themselves. In contrast, some teachers said the discussions are needed, especially in the context of racial issues:

> Teacher D: "It is relevant to 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 reports a lot, how they publish utter nonsense."

Half of the teachers did not identify any sensitive issue, which they would avoid. Among the other half there were differences in how they framed sensitive issues. Most of the argumentation was related to what is seen as biological general knowledge or avoiding misconceptions on genetics: teachers mentioned or implied that complex human traits are inherently so complex that there is a significant 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. 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.

Additionally, teachers mentioned how some issues are uncomfortable to them or to their students. Regarding students, some teachers acknowledged that discussing human heredity can pose several challenges (Table 2, Table S6). 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. The reason for describing these issues as "uncomfortable" was framed as a question of teacher not knowing how to deal with discussing these issues or encountering unexpected reactions from the students. 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 to be 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 by using different approaches

Teachers' perceptions of the most important genetic content were closely related to their willingness to use human context in their teaching or even what they said that students find interesting (Table 2). 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 group interviewed (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 more experienced teachers (> 20 years). A third approach, *Hereditary*, was characterised 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 who 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 colour as an example of polygenic traits. More broadly, in genetics, they usually emphasised 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 to how teachers taught GMOs (Table S2). 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 according to their genetics approaches. Furthermore, one teacher who said that they use GMOs as a motivation at the beginning of the course, to explain how genetics is important, said that they do not always have time to go into the ethics of GMOs. In general, lack of time is a general perception of teachers in many subjects and countries (Adams & Krockover, 1997; Archbald & Porter, 1994; Fuller, 1969) and the teachers also expressed this idea repeatedly. This reason worked in concert with the acknowledgement from most teachers that their teaching closely follows the textbook, and textbooks tend to discuss ethical dimensions of biotechnology at the end of the book (Aivelo & Uitto, 2015).

Teacher self-identification and relationship to actual teaching

When we provided teachers with the descriptions of the genetics approaches and our analysis of their interview, six teachers agreed with our analysis, three teachers disagreed and we could not contact one teacher (Table 2). All disagreeing teachers had their teaching approach labelled as Developmental. This disagreement is not a surprise as such, as the curriculum emphasises more structural and hereditary aspects and developmental biology as such is taught in another course. Two of the teachers also argued that their approach was not the one they would have preferred for genetics teaching, but it was mostly dictated by the national curriculum, which mentions evolution and development in different courses.

We obtained teaching diaries and other teaching materials with enough information for our analysis from five teachers. In categorization, the interrater reliability was high (Cohen's kappa: 0.88). The concurrence between interviews and diaries was variable as some teachers were fully concordant (such as teachers B and H), whereas Teachers G and J had two discordant categorizations (Table S7). In total, 18 of 22 analysing units were concordant between the interviews and diaries.

The model on factors influencing the choice of course content

Based on the interviews, we formulated a descriptive model on how teachers choose content for their courses (Figure 1). While most of the teachers interviewed said that they follow the textbook content closely, they still described their teaching in quite different terms. While the content choice of biology textbooks for upper-secondary school is highly similar (Aivelo & Uitto, 2015), teachers clearly had different priorities on the most important contents in genetics. All schools follow the national core curriculum, and this was evident in teachers' descriptions of their content choices. Furthermore, this was emphasised by the inclusion of SSI related topics to the study of GMOs in the biology core curriculum by all teachers. The National Core Curriculum is also the basis of the tasks on the matriculation examination and teachers acknowledged that previous exam questions guide their teaching.

The aforementioned factors similar for each teacher, but our results also reveal perceived differences among teachers and the circumstances in which they are working. Some of the teachers compared their school to other schools, and suggested that some attributes of their school attract students with specific interests or motivation or competence to study biology. Likewise, teachers described differences in course arrangements, and noted if it was possible to conduct experiments in the classroom. Furthermore, teachers expressed the view that there are personal reasons that affect their course content selection. On many occasions, the teachers acknowledged the limits of their competence, either regarding genetics content, such as when they are unable to answer students' complicated questions, or pedagogically, when they mentioned that they might have problems in guiding of classroom discussions successfully. Nevertheless, the approaches were an important component of teachers' descriptions of their teaching.

Discussion

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

Our findings suggest that there were fundamental differences in Finnish upper-secondary school biology teachers' perceptions of the most important themes in genetics and genetics teaching and subsequently how they chose course content and context while teaching genetics. Teachers' perceptions are reflected in how they choose different contexts to teach genetics content. These perceptions can be classified into three distinct teaching approaches, which we named *Structural*, *Hereditary* and *Developmental*. These approaches are formulated on the basis of what teachers interpret as 1) the central themes in genetics, 2) how they use human contexts in their genetics teaching and, 3) how they understand students' interest towards different contents and contexts.

While we have limited knowledge on the background of our interviewees, the teaching experience in years appeared to be a plausible reason for the different approaches of genetics teaching (Table 3). Contrary to previous studies (Hess, 2008; Phillips, 1997), our study showed that Finnish teachers were more open to discussions about complex human traits and other sensitive issues in the classroom if they were less experienced. All our interviewees had been teachers for most of their working career, thus, the experience was related clearly to 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.

Our findings are partly like those of Van Driel et al. (2007), who found separate subgroups of teachers who teach either subject-matter oriented focusing on fundamental, theoretical concepts or learner-centred emphasizing societal issues. While *Structural* approach can be seen as subject-matter oriented, *Developmental* approach is not learner-centred in similar sense as in Van Driel et al.'s study, as the orientation is not as much societal as it is personal. It is noteworthy, that teachers frame sensitive issues in relation to students personally, as something which concerns individual students and not as much as societally sensitive issues. Thus, there seems to be a trade-off between personal relevance to students and perceived problems arising from sensitive issues. As there were no differences in GMO teaching between approaches, teachers seem to be more hesitant about this personal relevance than they are about societal relevance.

Our results agree with Tidemand and Nielsen's (2017) suggestion that emphasis on biological content (as opposed to more societal context) is driven by teachers' identity as biology teachers. Moreover, 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 the science teaching orientations describe teachers' perceptions about teaching and especially instruction methods, we did not find that genetics teachings approaches would limit the instruction methods. Nonetheless, the different approaches raises the question of how differential teacher understanding of core concepts and contexts influences teaching methods or orientations to teaching science.

Teachers avoiding contexts

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 as being taught only "if there was time at the end of the course."

Teachers often discussed sensitive or controversial issues related to teaching human genetics on personal rather than a societal level. Furthermore, some teachers described avoiding human context which could be seen as being personally highly relevant to students. This avoidance is a complex issue as teachers used numerous reasons for steering clear, for example, of human genetics: a) students are not interested in these topics, b) teachers do not have enough content knowledge, c) teachers do not have the pedagogical knowledge for teaching sensitive issues and d) discussing genetics in human context would lead to negative learning outcomes, such as misconceptions. We are not able to assess how relevant these factors are, but it is clear from our teaching approach classification that there are fundamental differences in how teachers perceive what the more important content is and contexts in genetics. Genes and the gene concept have been widely studied as an example of a concept with multiple representations, and these representations can be reflected in what teachers see as the core content of genetics (Tsui & Treagust, 2004). For example, neither development nor evolution were mentioned as being part of the core content in the upper secondary biology courses related to genetics, but some teachers see these as the most important themes across the biological domain (Tsui & Treagust, 2013). Thus, we suggest that different understandings of what genes are and what the core content of genetics is can lead to very different teaching approaches.

Implications for research and teaching practice

While we do not suggest that the results are readily generalizable to other science teachers, some suggestions about transferability can be made. One reason for the rapid saturation may be the similarities in the educational background of the teachers, as all had a 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, the national curriculum for upper-secondary schools provides teachers with a substantial freedom 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. Consequently, in school practice, teacher education, and in-service training, the teachers should be made more aware and be provided with opportunities for self-reflection on the approaches they take in teaching science.

We also suggest that our content-choosing model (Figure 1) 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 to apply SSI-based approaches or sensitive human context to their teaching.

In light of GMO SSI being integrated in the teaching, independent of teacher inclinations, we suggest that curriculum development would be a valuable approach if the aim of genetics education is to incorporate societal and personal relevance better. 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 and avoidance of human related topics, there is a perceived lack of useful and tested teaching materials. Content knowledge is important for successful reasoning regarding SSI: thus, a delicate balance needs to be sought (Lederman et al., 2014; Sadler & Zeidler, 2004)

From our interviews, it is clear that personal relevance in teaching can be a double-edged sword in the classroom: while some teachers see it as an option, some seem to avoid it for a number of reasons. This needs to be addressed more in professional development. In general, the ways to teach controversial issues are not well-studied and the recommendations themselves are controversial (Christopher Oulton et al., 2004). Thus, both societal and personal relevance should be taken more into account in science and especially in biology teacher education and in-service training.

Conclusions

Based on a qualitative case study and teacher interviews, we have built a model of how upper-secondary school teachers choose which content they emphasise in genetics teaching. 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 genetic phenomena.

Teachers' perceptions reflected three 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 societally and personally relevant contents occurred in the less experienced teachers, while more experienced teachers commonly had a structural approach, which could even consist of avoidance of discussing sensitive issues. As we did not observe the teaching practice, we do not know how well these approaches are manifested 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 their teacher's genetics teaching approaches.

Our results revealed several approaches to genetics teaching, which led to an emphasis on different content and context and an avoidance of certain topics, such as discussing personally or societally relevant issues. These approaches were related to teacher experience as more experienced teachers were less likely to discuss sensitive or controversial issues. We also argue that curricular development is an effective way to increase the prominence of societal or personal relevance in biology education.

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Appendix

Supplemental material in Figshare includes following tables containing representative quotes from teacher interviews:

Table S1: Teacher's descriptions of the central theme of their teaching.

Table S2: Teacher's descriptions of GMOs in their teaching.

Table S2: Teacher's descriptions of the human Mendelian disorders in their teaching.

Table S3: Teacher's descriptions of the complex human traits in their teaching.

Table S5: Teacher's descriptions of the perceived student interest in genetics.

Table S6: Teacher's descriptions of perceived sensitive issues.

Table S7: The concurrence between teaching diary and other materials in comparison to teacher interviews.

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Table 1: 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

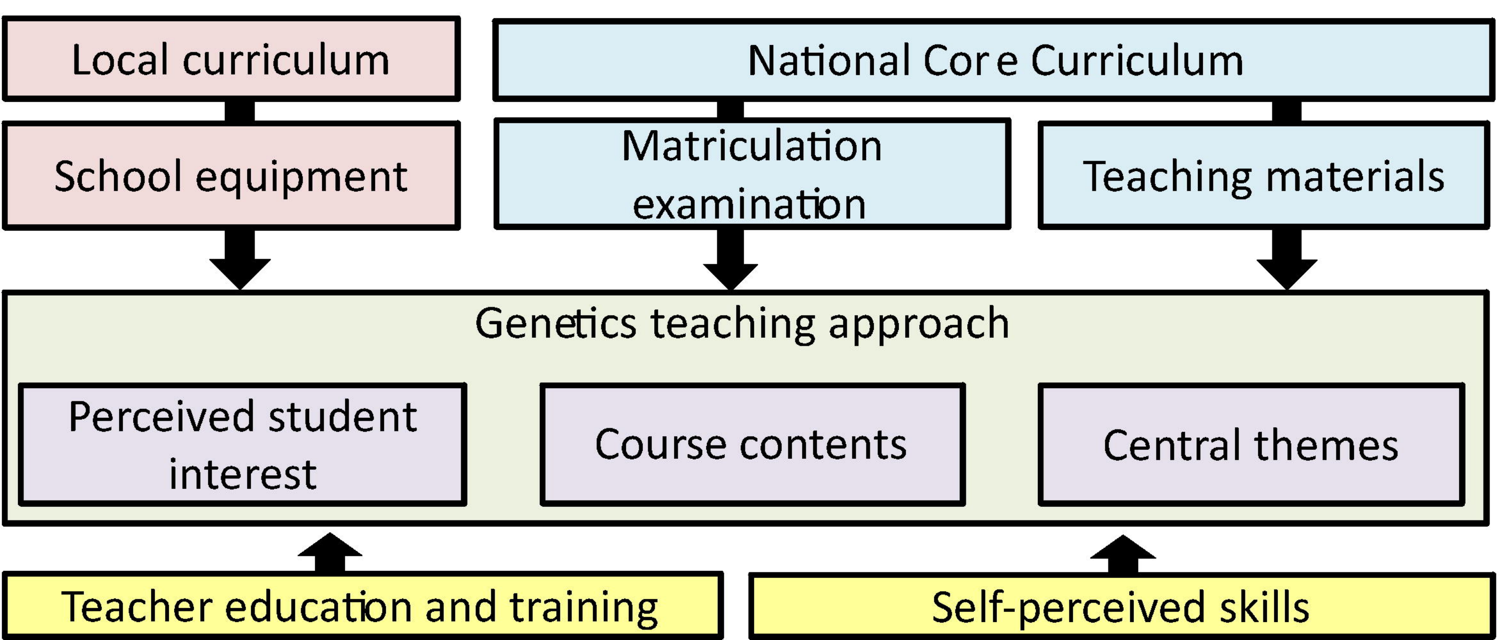
Table 2: Summary of interviews of ten interviewed teachers. For details, see the supplemental material.

Teacher	Experience in years	Gender	Central theme of teaching	Examples of Human Mendelian traits	Examples of Complex human traits	Perceived sensitive issues	Perceived student interest	Genetics teaching approach	Teacher concurrence with analysis
A	3	Female	Development of phenotype	Disorders, lactose intolerance	Life style diseases	None	Artistic talent, epigenetics	Developmental	Yes
B	12	Male	Development of phenotype	Disorders, blood groups, tongue roll	Height, skin colour, talent	None	Epigenetics, talents, monohybrid crosses	Developmental	Yes
C	27	Female	Inheritance and continuity	Disorders	Eye colour, **generally avoid**	Intelligence	Gene tests	Hereditary	Yes
D	7	Male	Inheritance and continuity	Disorders	Height, skin colour	Human race-related	Medical genetics	Hereditary	No answer
E	26	Male	The structure and function of genes	Eye colours, **generally avoid**	Shoe size, **generally avoid**	Intelligence	Mono- and dihybrid crosses	Structural	Yes
F	11	Female	Development of phenotype	Disorders, tongue roll, widow's peak	Height	None	Challenging contents	Developmental	No; Structural
G	20	Female	The structure and function of genes	Tongue roll, eye colours, **generally avoid**	Height, hair colouration, **generally avoid**	Intelligence, talent, genetic disorders	Mono- and dihybrid crosses	Structural	Yes
H	8	Female	Inheritance and continuity	Tongue roll, ear lobe	Skin colour, generally avoid	None mentioned	Inheritance patterns	Hereditary	Yes
I	9	Male	Development of phenotype	Disorders	Stress reaction, intelligence	None	Sex-related traits	Developmental	No; Structural
J	6	Female	Development of phenotype	Disorders, eye colour, ear lobe	Height, skin colour	Developmental disorders	Musicality, own complex traits	Developmental	No; Hereditary

Table 3: Three teaching approaches and the teacher perceptions and descriptions which differ between approaches.

Teaching approach	**Structural**	**Hereditary**	**Developmental**
Central theme	Gene structure and function	Continuity of DNA through time	Development of traits
Human context			
1. Human Mendelian disorders	Avoid	Use as examples	Use as examples
2. 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: A summary of factors relating to teachers' emphasis on different genetics teaching approaches. The model is composed of three groups: national core curriculum, teaching, and assessment materials 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 visualise connections between items: for example, the National Core Curriculum influences matriculation examination questions and teaching materials, which both influence course content.


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