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Factors explaining students' attitudes towards learning genetics and belief in genetic determinism

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ABSTRACT

Understanding how teaching affects students' attitudes and beliefs is notoriously difficult, specifically in a quickly evolving and societally relevant field such as genetics. The aim of this survey study is to capitalize our previous research and examine how teaching relates to Finnish secondary school students' liking of, self-concept in and experienced utility of genetics, attitude towards gene technology and belief in genetic determinism. In this unique setting, we used as explanatory variables their teachers' teaching emphases and learning materials, and as student-related factors, we used gender and the number of biology courses attended. Item-response theory with exploratory, confirmatory, and explanatory analyses were carried out to model the data. Teaching explained students' attitudes and beliefs: if the teacher's emphasis was Hereditary or the textbook with stronger Mendelian emphasis was used, students tended to have more negative attitudes towards learning genetics and stronger belief in genetic determinism . Our results also suggest gender differences: male students had more positive attitude towards gene technology, higher self-concept, whereas as utility of genetics and belief in genetic determinism were higher in females. The results suggest that teaching' approaches as well as learning materials need updates to fulfil the needs for genetics literacy.

Introduction

As a form of scientific literacy, genetics literacy has been presented as a required skill in the twenty-first century (Boerwinkel et al., 2017). More and more technological advances, which might shape society and human beings themselves, are available to a wider audience. Several genetics-related issues already are or are expected to become widely relevant policy issues: gene technology in food production or disease treatment, genetic tests on animals and humans, and study of human ancestry through population genetic tools. Nevertheless, the teaching of genetics has been

slow to follow new societal importance of genetics literacy. Consequently, there has been a debate on the teaching of genetics, the focus of genetics teaching and the role of societal issues in teaching (Chapman et al., 2019; McElhinny et al., 2014; Redfield & Kerfeld, 2012; Smith & Gericke, 2013).

Indeed, it is important to know how current teaching approaches and learning materials influence students' attitudes towards genetics and socio-scientific issues (SSI), such as gene technology and genetic determinism. We present a survey study of Finnish upper secondary school students (grades 10–12, ages 16–19) on their attitudes towards studying genetics and the use of gene technology, and belief in genetic determinism. Our prior studies with the same respondents have shown that their teachers used differing emphases in teaching genetics (Aivelo & Uitto, 2019), so that they emphasised either gene structure and function (*Structural* emphasis), continuity of DNA throughout evolution (*Hereditary* emphasis), or genotype-to-phenotype link (*Developmental* emphasis). These emphases are not only content-related, but they also pertain to how teachers perceive student interests in genetics and how much they use human contexts in their teaching. We have also analysed the contents of the biology textbooks used by the same students (Aivelo & Uitto, 2015) and the results indicated that while the textbooks are highly similar in contents and ordering of the contents, they do contain substantial differences in which gene models are used (c.f., Gericke, 2008).

Consequently, in this study, we have a unique setting to tease apart the relationships between genetics teaching, textbooks, and student attitudes. The aim of the present study is to discover the relative importance of teacher- and student-related factors on student attitudes towards learning of genetics and gene technology as well as their belief in genetic determinism

Attitudes towards science learning in school

An attitude has been defined as an immediate disposition towards concrete or abstract objects, events, or people in one's environment, with some degree of favour or disfavour (Eagly & Chaiken, 1993; Potvin & Hasni, 2014). In science education, general and impersonal evaluation perspectives are decisive for an attitude (Krapp & Prenzel, 2011). According to Osborne et al. (2003), attitudes towards science and science education do not consist of a single construct, but a large number of subconstructs that to varying degrees shape attitudes towards science. For instance, anxiety towards science, enjoyment of science, belief in the utility of science, and self-esteem vis-à-vis science reflect different aspects or dimensions of students' attitudes towards school science. In science education, biology is commonly found to be a favourite subject, especially among young women (Britner, 2008; Osborne et al., 2003; Uitto, 2014)

While genetics is commonly given as an example of a difficult topic in biology learning (Bahar et al., 1999; Banet & Ayuso, 2000), there are not many investigations of factors relating to students' attitudes towards learning on genetics and its applications. For instance, Taiwanese primary and secondary school students found

genetics interesting, important, and relevant, but also difficult and too mathematical, though their attitudes were less polarised the older they were (Chu, 2008).

Attitude towards gene technology

There is a positive relationship between knowledge and attitudes towards science in general (Allum et al., 2008) and this is true also for gene technology (Casanoves et al., 2015; Sturgis et al., 2010). Nevertheless, while an understanding of genetics is generally limited among the members of the general public, they have often been found to have positive attitudes towards gene technology (Henneman et al., 2006) and the attitudes are becoming even more positive (Henneman et al., 2013).

Gene technology is an essential content in the upper secondary school curriculum. For instance, the Finnish National Board of Education (FNBE, 2003) emphasises students' understanding of the importance of gene technology in, for example, medicine and industry. Also, the students should have skills to assess the opportunities, threats and ethical issues linked to gene technology to make informed decisions. Thus, attitudes towards gene technology is important to study as they may relate to students' attitudes to learn genetics in the school. Similar to attitudes towards science, attitudes to gene technology are likely to be multidimensional. In their review on students' attitudes towards gene technology, Gardner and Troelstrup (2015) found the construct to be formed of five subconstructs, relating to acceptability, research, moral and ethical issues, regulation risks and trust. In our study we wanted to focus on the acceptability of the use of gene technology because this construct relates mostly to the biology curriculum.

Many personal, social, and cultural backgrounds form the framework in which students' attitudes towards gene technology can develop. For instance younger students (12-year-olds versus 17-year-olds) have less favourable attitudes towards biotechnology (Dawson, 2007), suggesting that either formal or informal education with increasing scientific literacy or evolving attitudes during one's lifetime may lead to more favourable attitude towards biotechnology. Nevertheless, Klop and Severiens (2007) suggest that students holding negative attitude towards biotechnology can belong to two different groups: those not interested in biotechnology at large and not well-informed and those who have high knowledge, but deeply skeptical attitude towards personal or societal use of biotechnology. Large international surveys, such as Programme for International Student Assessments (PISA) has shown that male students tend to be more favourable towards science and technology than female students (OECD, 2013). This seems to the case also in gene technology (Črne-Hladnik et al., 2009; Kidman, 2010), although, gender preferences are more linked to pedagogical contexts and students' own life experiences than to disciplines (Fonseca et al., 2012; Potvin & Hasni, 2014). Thus, it is important to study in more detail, what is the relative importance of gender and educational factors in shaping students' attitudes not only towards learning genetics but also towards gene technology.

Belief in genetic determinism

One of the central misconceptions repeatedly raised in genetics teaching and learning is genetic determinism. While biology as a science subscribes to a level of genetic determinism as genes are responsible for guiding development of individuals, in the research of

science education, genetic determinism refers to much stronger version of this idea. In this context, genetic determinism 'is the belief that genetic contributions to phenotypes are exclusively or at least much more important than the contributions of other factors such as epigenetic and environmental ones, even in the case of complex traits such as behaviors and personality' (Carver et al., 2017). Carver et al. (2017) also suggest that in lieu of a deterministic model, the current scientific model is rather 'multifactorial' or 'probabilistic.'

While genetic determinist discourse has long been rife in public representations of genetics research in the mass media (Nelkin & Lindee, 1995), it is less clear how the audience may have understood it. More recently, we know from a number of studies that public knowledge of genetics is limited (Allum et al., 2008; Chapman et al., 2019; Mielby et al., 2013), and that the public displays genetic deterministic thoughts (Condit et al., 2009), but whether this is due to deterministic genetic representations in the media or formal education is unknown. Previous studies show that the same deterministic representations are also common in school textbooks (Carvalho dos Santos et al., 2012; Castéra et al., 2008; Gericke et al., 2014), and in student texts (Lewis & Kattmann, 2004; Shaw et al., 2008).

Genetic determinism is usually manifested through the belief in a one-to-one relationship from genes to traits. There is a debate whether genetic determinism is simply a misunderstanding or simplification of science, or more related to deeply held beliefs, religious or otherwise. For a few reasons, strong genetic determinism might not be a misunderstanding. Firstly, general knowledge about genetics and beliefs in genetic determinism do not correlate well (Castéra & Clément, 2014; Gericke et al., 2017). Secondly, there is evidence that determinism relates to a genetic essentialist belief that, echoes a plethora of intolerant attitudes, such as racism or eugenics (Dambrun et al., 2009; Shostak et al., 2009). Thirdly, these innatism ideas can correlate between non-tolerant attitudes (Castéra & Clément, 2014). Nevertheless, it is not well known how these issues relate to students' learning about and attitudes towards genetics, though as an exception, Jamieson and Radick (2017) showed in their exploratory teaching intervention that developmental context emphasis leads to less determinism in university students.

Study context and aims

We have an ongoing research project on genetics education in Finland, including textbook analysis (Aivelo & Uitto, 2015) and teacher interviews (Aivelo & Uitto, 2019). We aimed to understand how this interplay between textbooks and teacher perception of genetics teaching mirrors student attitudes towards learning genetics, the societal use of genetics, and genetic determinism. We outline here Finnish curriculum related to teaching genetics, different textbooks and teacher's emphases on genetics teaching, but provide more information in Supplementary Material.

Genetics is taught in Finland mainly as a part of biology courses. The national core curriculum (Finnish National Board of Education, 2003) consisted of two mandatory courses and three optional courses. The second mandatory course is Cells and Heredity, which contains molecular and cell biology and basics of inheritance, and the third optional course is Biotechnology, which includes further genetics, microbiology and

gene technology. As core curriculum provides freedom for teachers to decide on their teaching methods and materials, there is variation in how teachers teach genetics (Aivelo & Uitto, 2019). Genetics is a very minor part of biology teaching in lower secondary schools in Finland and we would expect that upper secondary school biology teaching has an impact on how students will perceive genetics.

In Finnish upper-secondary school, the biology textbooks are highly similar concerning genetics content: in our previous study (Aivelo & Uitto, 2015), we found that the main differences between two books were that Textbook 1 contained more recent gene models, while Textbook 2 had stronger Mendelian approach. Textbook 1 also contained a specific chapter on environmental effects on phenotype, which was not covered in Textbook 2. Thus, Textbook 2 presented genetics in a predominantly Mendelian context, while Textbook 1 also links inheritance to molecular genetics and environmental effects. We refer here Textbook 1 as *Environmental* and Textbook 2 as *Mendelian* as a distinction between the books.

Teacher emphases in genetics teaching were analysed in Aivelo and Uitto (2019). In brief, teachers using a *Developmental* emphasis see genetics through development of traits, like to use a human context, and perceive their students as being interested in complex human traits and epigenetics. Teachers using a *Hereditary* emphasis focus on the continuity of DNA through time, use humans as a context for Mendelian disorders but not for complex human traits, and perceive students to be interested in gene testing and medical genetics. Teachers using a *Structural* emphasis concentrate on gene structure and function, avoid discussing a human context, and perceive that students are interested in monohybrid and dihybrid crosses. These emphases are based on teachers' own descriptions of their teaching, and they do not describe teachers' emphasis on any individual teaching situation, but rather what teachers see genetics to constitute from a teaching perspective.

In order to find out the importance of teacher- and student-related factors on student attitudes towards learning genetics (Metsämuuronen, 2012; Osborne et al., 2003) and gene technology as well as their belief in genetic determinism (Carvalho et al., 2008), we used item response theory (De Ayala, 2009). We modelled the relationship between previously studied textbooks and teachers' emphasis and attitudes and beliefs based on student questionnaires.

Our research questions were

RQ1: What attitudes and beliefs do the students have towards learning genetics when measured as

a. experienced liking of, self-concept in and utility of genetics as a topic of learning
b. attitude towards the use of gene technology and
c. belief in genetic determinismRQ2: How are students' attitudes towards learning genetics and beliefs in genetic determinism explained by student and teacher-level factors, namely
d. gender
e. number of biology courses attended
f. textbooks content emphasis
g. teacher's emphasis in genetics teaching

Table 1. The sample size from different schools, teachers with different teaching emphasis and used textbook.

Teacher	Number of student answers	Teacher emphasis in genetics teaching	Used textbook
A	25	Developmental	Textbook 1
B	49	Developmental	Textbook 1
C	53	Hereditary	Textbook 1
D	47	Hereditary	Textbook 1
E	42	Structural	Textbook 1
F	19	Developmental	Textbook 1
H	65	Structural	Textbook 2
I	55	Hereditary	Textbook 1
J	37	Developmental	Textbook 1
K	29	Developmental	Textbook 2

Material and methods

This study is a part of a larger study on genetics teaching, also encompassing textbooks and teacher perceptions of genetics teaching (Aivelo & Uitto, 2015, 2019). We distributed questionnaires with the help of biology teachers whom we had interviewed previously about genetics teaching. We had purposively selected 10 upper-secondary school biology teachers from Southern and Western Finland to capture a variation in teacher experience and gender, type of school and location in order to access variable student populations for the questionnaire (Table 1). All teachers had biology as a major subject in their university master's degree.

Questionnaire

We collected questionnaire data from the students during the school year 2015–2016 (Table 1). We asked teachers to present the questionnaire to the students during the school day throughout the school year when they had mandatory *Cells and heredity* and optional *Biotechnology* courses (see FNBE, 2003) after most of the course has been completed.

To study the students' attitudes and beliefs, two different survey instruments were combined (Table S1). Firstly, we used a modified version of Fennema Sherman Mathematics Attitude Scale (FSMAS) (Fennema & Sherman, 1976) to investigate students' attitudes towards learning genetics. The questionnaire has been previously used in international assessments of learning (TIMMS and PISA) to measure students' attitudes towards learning mathematics (Metsämuuronen, 2012) and in Finnish national achievement test to measure students' learning in different science subjects (Metsämuuronen, 2012). The shortened FSMAS is composed of three different subconstructs, *Liking, Self–concept* and *Experienced utility in a specific school subject*, respectively (Fennema & Sherman, 1976). *Liking* was modified to measure positive affect towards learning genetics, *Self-concept* students' confidence in their ability to learn genetics and *Experienced utility* students' perception of genetics achievement as advantageous to their future education and the world of work. Secondly, we used the Biohead-Citizen questionnaire (Carvalho et al., 2008; Castéra & Clément, 2014; Clément et al., 2007) designed to measure students' systems of values related to the genetic knowledge. We chose and modified

the items from the original questionnaire to create two unidimensional separate constructs *Attitude towards gene technology* and *Belief in genetic determinism*. *Attitude towards gene technology* was mostly formed from items related to the Utilisation factor and Human genetics factor which relates to usefulness and the acceptability of the use of natural resources and genetic modification to advance human wellbeing, whereas *Belief in genetic determinism* was based on items on Human genetics/Genetic determinism factor which measures belief in genetic determinism of personal or individual features.

The questionnaire was built on five items per each five constructs with five-point Likert-scale items ranging from 'I strongly disagree' to 'I strongly agree'. The questionnaire included background information on students, including gender, age, the number of attended biology courses, the textbooks they have used, and a few short open-ended questions that were not analysed for this study.

Statistical analysis

To study the connections of background variables on teachers and students, students' attitudes towards learning genetics, their attitudes towards gene technology and belief in genetic determinism, the collected data was modelled using multidimensional item response (latent trait) theory framework. This allows us to understand the student- and teacher-level factors explaining variation in the factors outlined by our questionnaire's Likert-scale items. IRT considers each item individually; thus, it allows for items on the same scale to have different response curves to latent traits (Bortolotti et al., 2013). We present more details in Supplementary Materials but outline here the general approach.

Our strategy contains three phases: an exploratory item analysis to examine the data structure and its suitability for our purposes, confirmatory analysis to test the factor structure of the preliminary model, and the explanatory analysis to model latent traits. While it is suboptimal to use the same dataset for both exploratory and confirmatory analysis (Reckase, 2009), it should not be a problem with this study, as the factors were already determined at the beginning of the study. Thus, the first two phases are largely quality control and not theory-forming phases.

We explored the usability of our items with exploratory item analysis (Gorsuch, 1997). We set the expected number of factors to five and allowed all items to load freely to any of these five factors. Then we compared the resulting factor loadings to the expected pattern of factor loadings. We modelled items with a generalised partial credit model (GPCM; Muraki, 1992) and used estimation with Metropolis-Hastings Robbins-Monro (MH-RM) algorithm (Cai, 2010b, 2010a). The resulting model converged (i.e. reached a convergence threshold of 0.001) relatively quickly (with fewer than 300 iterations). After the observation of modelled factor loadings, we dropped items that performed poorly (i.e. those that had evidence of multidimensionality, or a lack of loading in any factors). We further validated our items and answers by implementing confirmatory item analysis along the same properties as the exploratory analysis and removed poorly fitting items and respondens (details can be found in Supplementary material).

After validating items, factors, and answers, we built mixed effects item response theory models in a generalised linear mixed modelling framework with person level

covariates and random effects (Chalmers, 2015). The model included student-level factors gender and total number of biology courses, and teacher-related factors textbook (1 and 2) and teacher emphasis in genetics teaching as fixed effects, while school was added as random factor. Model was validated by convergence during model iterations.

The raw data is provided in Figshare (doi:10.6084/m9.figshare.12356336.v1) and code is shared in GitHub (https://github.com/aivelo/genesurvey). All phases of the analysis were run on R (R Core Team, 2013) with the package 'mirt' (Chalmers, 2012).

Ethical viewpoints

Permission to conduct the study was requested from the municipalities, which are in charge of education in Finland; each school principal and every participating teacher was also invited separately. The questionnaires distributed to students contained information about the study and the students participated voluntarily. All participating schools, teachers, and students are anonymised in the research data.

Results

### General characteristics of the data

We had a total of 421 respondents from 10 different schools, with a range of 19–65 responses per school (Table 1). The response rate was higher than 90% for each group. 62.9% of the respondents were females, 33.0% were males and 4.1% did not answer or chose 'other' option. The mean age of the respondents was 17.8 (± 1.9) years, and the mean total number of biology courses was 3.5 (± 1.8).

Most of the respondents used the Environmental Textbook 1 book (77.7%), while a minority used Mendelian Textbook 2 (22.3%). Respondents were quite uniformly distributed from each of the teachers' emphasis in genetics teaching (Developmental: 37.8%, Structural: 25.4% and Hereditary: 36.8%).

In exploratory IRT modelling, we recovered our initial expected factors, though some items performed unexpectedly (Table S2). We removed items 17, 20, and 24, as they did not load in a meaningful way in any of the factors, and items 6, 14, and 23 as there was multidimensionality in loading to various factors. All the factors had at least three well-performing items in them (Figure 1, Table S3). Confirmatory model showed a good fit (RMSEA = 0.051 (0.040–0.062), TLI = 0.957, CFI = 0.968). Seventeen respondents did not fit the model; consequently, they were removed from downstream analysis. Lastly, the explanatory model converged after 854 iterations, when it reached a standard error tolerance criteria of under 0.001. Variation among schools was significant, but comparably low as random effect covariance was only 0.12 (95% CI: 0.02–0.22). The details of the model outputs are presented in the following sections.

### Student-level factors: gender and number of courses in biology

In explanatory model, female and male students had significantly different responses along four of the five attitude factors: liking genetics was the only factor without
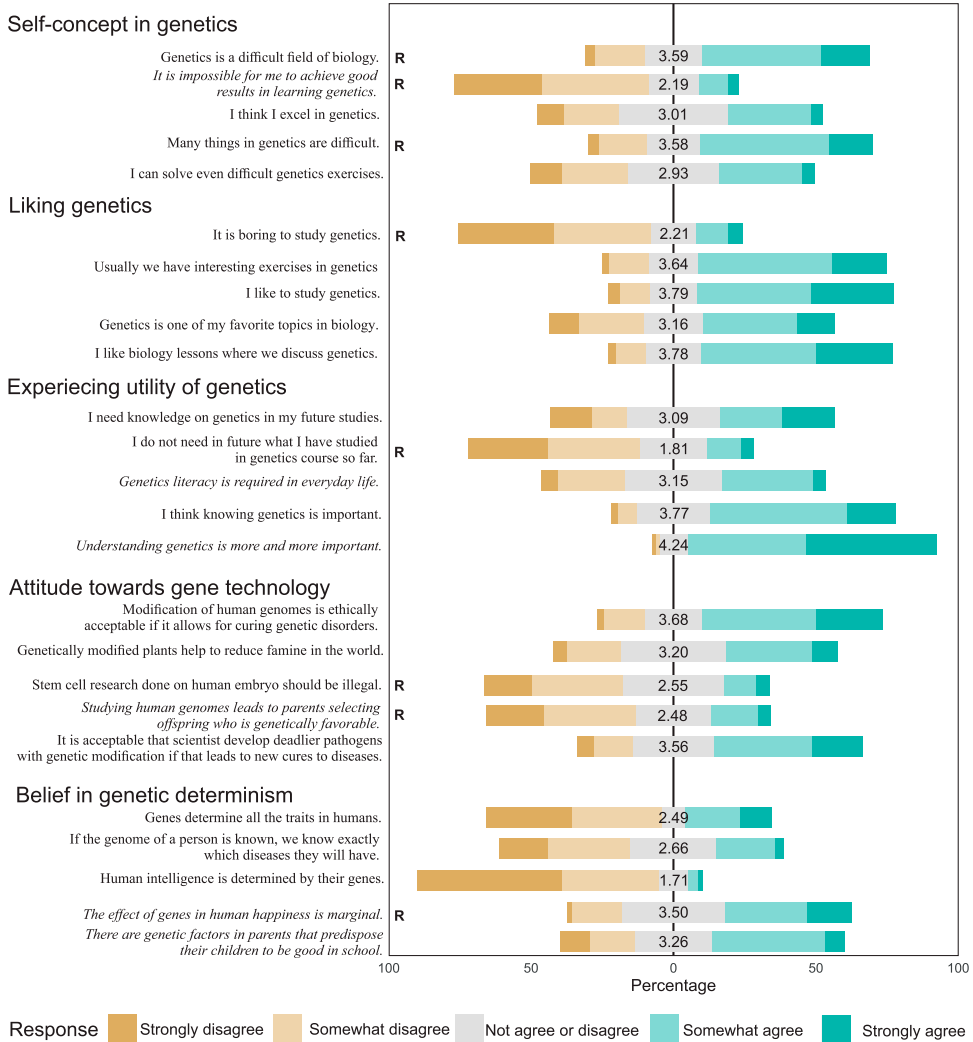
Figure 1. The distribution of the responses for each item included in the final scale. The items are grouped by factors to which they belong (left side). The value in the middle of the bar represents the mean for each item (from 1 = strongly disagree to 5 = strongly agree). The item-related statistics are shown in Table S2 and S3. For the analysis, the items marked with R were reversed and the items in italics performed poorly and were removed.

gender difference (Figure 2). When compared to females, males had a more permissive attitude towards gene technology and their belief in genetic determinism was weaker, respectively. Furthermore, males experienced less utility in genetics and they were more self-efficient in genetics on average than females.

The other person-level factor in the model was the number of attended biology courses: those students that had attended more biology courses so far, had significantly more permissive attitudes towards gene technology, but also a stronger belief in genetic determinism; they experienced more utility in genetics, they were more self-efficient and they liked genetics more (Figure 2) than students who attended fewer biology courses.
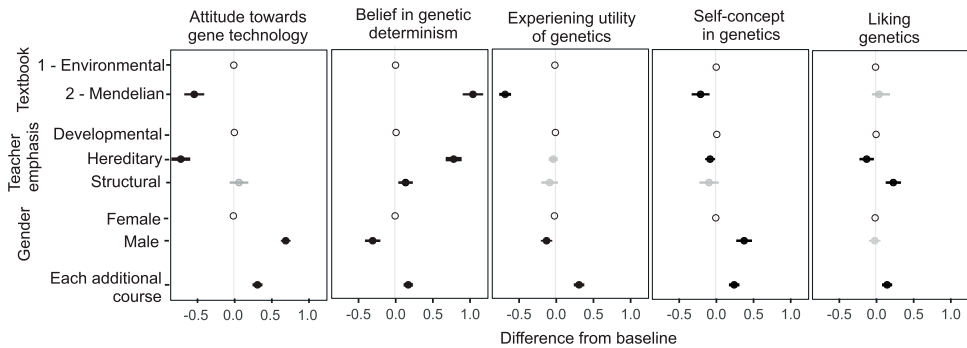
Figure 2. Links between student- and teacher-related variables and student attitudes. For each variable, one level is chosen as a baseline (Textbook 1, developmental emphasis of the teacher and female students) and this is represented by unfilled circles. Values substantially differing from baseline as shown with 95% confidence intervals are colored black, while values with no significant difference from baseline are colored gray.

Teacher-level factors: emphasis in genetics teaching and used textbook

We included two teacher-level factors in the models: used textbook and teacher's emphasis on genetic teaching. This revealed strong differences in students' attitudes among the teachers using different textbooks: the students of the teachers using Mendelian Textbook 2 had less permissive attitude towards gene the use of gene technology, a much stronger belief in genetic determinism, they experienced less utility in genetics and they were slightly lower self-concept in learning genetics. (Figure 2).

Teacher's emphasis on genetics education also affected the students' attitudes (Figure 2): teachers with *Hereditary* emphasis had students who exhibited less permissive attitudes towards gene technology and much stronger belief in genetic determinism in comparison to Structural or Developmental emphasis. Furthermore, the students taught by the teachers with a *Hereditary* emphasis had a lesser self-concept and less liking of genetics. Teachers with a *Structural* emphasis had students who exhibited a slightly stronger genetic determinism than teachers with *Developmental* emphasis, while their students had the highest level of liking of genetics. Notably, students' perception of the utility of genetics did not differ among teachers' emphases.

Discussion

As genetics is of growing importance, there is a burgeoning number of individual studies on genetics education, but a lack for more comprehensive synthesis. We present here a modelling-based study on our previous analysis of textbook contents and teacher interviews with additional student questionnaires, thus bringing together commonly separately studied aspects of science education. Our model explained the impact of both teacher- and student-related factors on secondary school students' attitudes towards learning genetics and the use of gene technology and their belief in genetic determinism. In student-related factors, gender differences were found in most of the attitudes, whereas the number of attended biology courses significantly explained differences in all attitude and belief dimensions. Surprisingly, differences in students' attitudes were

also to a large degree explained by teacher's emphasis in genetics teaching as well as the content emphasis of the biology textbooks. To our knowledge, this is the first empirical evidence that teaching Mendelian and classical genetics with an emphasis on hereditary aspects can lead to genetic deterministic conceptions.

Our study suggests that in general, the students liked to study genetics; they had mostly favourable attitude towards gene technology and they did not hold strong belief in genetic determinism. These findings are in line with the present studies that overall civic attitudes towards gene technology are favourable in many European countries (EFSA, 2019; Henneman et al., 2013; Snell & Tarkkala, 2019).

The role of student-related factors

We found that students' orientation and increasing knowledge of genetics, here roughly estimated as the number of attended biology courses, has a low, but consistent correlation with students' attitudes and beliefs. The number of attended biology courses explained more favourable attitudes towards learning genetics, but unexpectedly also students' stronger belief in genetic determinism.

The implicated connection between studying more biology and having stronger belief in genetic determinism surprises as such belief contradicts current scientific understanding of multifactorial gene function (Carver et al., 2017). The result contrasts to Chapman et al. (2019) who found a negative correlation between genetic knowledge and genetic deterministic ideas. Notably, Gericke et al. (2017) did not find any relationship between genetic knowledge and genetic determinism among Brazilian university students, and Castéra and Clément (2014) did not find any difference between innatist ideas between European and Mediterranean biology teachers and non-biology teachers.

There might be several reasons for the result: for example, both studied textbooks have been shown to exhibit a number of genetic determinist representations (Aivelo & Uitto, 2015); indeed, deterministic views are common in school textbooks (Carvalho dos Santos et al., 2012; Castéra et al., 2008; Gericke et al., 2014). Thus, by studying with such textbooks with emphasis on Mendelian genetics, the students might pick up stronger genetic determinism (although this might have not been the original intent of the textbook writers). Obviously, the causality can also be reversed: those students who think more strongly about genetic determinism are more likely to study genetics, as they feel it as more important to understand. Indeed, there was a positive correlation between belief in genetic determinism and experiencing utility in learning genetics (Table S4).

As expected, the students who had attended more courses in biology, also liked genetics more, had higher self-concept and experienced a stronger utility for knowing genetics. The students who attended more courses in biology had obviously their specific interest and motivations to learn more about biology and genetics. The strongest relationship between the number of attended courses was with the positive attitude towards the use of gene technology. This suggests that the students who study the most biology also either become or already are more positive towards gene technology.

Reasons behind gender differences are not often discussed in the research of genetics education. As found in many studies gender differences were evident in some factors:

male students had more positive attitudes towards gene technology (Mielby et al., 2013; Olofsson et al., 2006; Sturgis et al., 2010) and higher self-concept in learning genetics (Fonseca et al., 2012; Prokop et al., 2007). In our study male respondents had weaker belief in genetic determinism than females, whereas in a previous study on university students Gericke et al. (2017) did not find gender differences at all. However, our results showed that the gender effect was smaller than the effects of teachers' and textbooks' emphasis on students' attitudes and beliefs. In general, educational arrangements can affect students' attitudes and beliefs in science education more than gender (Osborne et al., 2003; Potvin & Hasni, 2014).

The role of teacher-related factors

We found that biology textbooks and teacher emphases, defined as *Structural*, *Hereditary* and *Developmental* (Aivelo & Uitto, 2019) correlated more strongly than expected with student attitudes towards learning genetics. Most notably students whose teacher used a *Hereditary* approach had much stronger belief in genetic determinism than students whose teachers used a *Developmental* or *Structural* approach in their teaching. Furthermore, the *Hereditary* approach correlated strongly with students' negative attitude towards the use of gene technology. A *Structural* approach in turn correlated with higher liking in genetics, while *Hereditary* was linked to lower, when the results are compared to the *Developmental* approach of the teacher. These results were unexpected in a sense that in our previous analysis *Hereditary* emphasis was seen to be a conceptual middle ground between a human-contextualised *Developmental* approach that focuses on the genotype to phenotype link, and the *Structural* approach that focuses on gene structure and function, but in which human-context was avoided (Aivelo & Uitto, 2019).

Textbooks are a dominant resource for the science classroom, and, in general, the textbook chosen by the teacher contributes to students' genetic and scientific literacy in many ways (Calado et al., 2015; Osborne et al., 2003). In our study, the difference between the students using either of the textbooks was substantial in many ways. Most notably, in our model the use of Mendelian Textbook 2 explained students' stronger belief in genetic determinism. Furthermore, the learners using Mendelian Textbook 2 had a lower self-concept and they experienced less utility in genetics; they also had a less permissive attitude towards the use of gene technology. Mendelian Textbook 2 emphasised less the environmental effects on phenotype formation, suggesting a link between stronger genetic determinism and lack of discussion of environmental effects in genotype to phenotype link (Aivelo & Uitto, 2015).

All in all, our results suggest that there is a potential link between currently used teaching emphases or materials and student conceptions in genetics. Originally outlined by Gericke and Hagberg (2007), a link between the emphasis on teaching Mendelian genetics and genetic determinism has been suggested since in numerous studies (Donovan, 2014; Gericke & Smith, 2014; Jamieson & Radick, 2017). Previous studies have outlined a number of properties, which have been speculated to have an effect on learning deterministic misconceptions, such as misleading metaphors, multiple representations of genes and ahistorical gene models. While our research does not allow for pinpointing which properties in emphases or textbooks are the most impactful in learning

misconceptions, they underline the importance of looking more closely to the details of genetics teaching.

Limitations of the study

We had five items per factor and while this might cause suboptimality in the modelling of the factors due to low number of items, the items seemed to perform adequately, and the model was successfully parametrised. In Genetic determinism items, there was a distinction between items as the students described quite high agreement with two items on medical genetics, while having low agreement with the item on human intelligence. This seems to be in line with the findings of Gericke et al. (2017), suggesting that the belief in genetic determinism consists of two dimensions: social behaviour and biological traits, and our findings seem to be compatible with theirs (but see criticism in Tornabene et al., 2020). These results also align with interview studies (Andreychik & Gill, 2015; Condit et al., 2009). The items of our study measured acceptability and ethical issues, which according to Gardner and Troelstrup (2015) are different constructs. However, our items are similar to factor called by Klop and Severiens (2007) as 'basic emotions on biotechnology'. As our items performed rather well as one factor, this suggests that more research is needed to understand the different dimensions of students' attitudes towards gene technology.

It should be noted, though, while there is no expectation that teachers with different emphases are non-randomly distributed in schools, the textbook selection is most likely not random. Teachers usually choose textbook series, which they like, and find more suitable for their students. As teacher emphases are based on what teachers perceive as the most important contents and contexts in genetics teaching, their emphasis probably affected the textbook choice. Furthermore, Textbook 2 was used only by two teachers, thus limiting the sample size.

We do not know what kind of teaching emphases the earlier biology teachers or classroom teachers in primary and lower secondary school have used, and the role of prior content knowledge about genetics might play a substantial role. Nevertheless, genetics plays a minor role in primary and lower secondary school. Thus, we would expect that genetics would be one of the fields of biology where the impact of the biology teachers would be most noticeable in Finnish upper secondary school. This study also further validates the existence of these approaches as there are clear differences between teachers using different teaching approaches.

Implications on teaching practices

Though we compared only two textbooks, either of them is used by almost all upper secondary school students in Finland. The differences highlighted the importance of teachers making informed choices when they select textbooks. While not much studied, textbook contents have been shown to significantly influence student interest (Kloser, 2013). In Finland, the selection of textbooks is generally up to each individual teacher, thus they have a responsibility for choosing suitable textbooks. As outlined by Johansson (2006), textbooks not only make learning possible, but also function as an obstacle to learning; therefore, they should be carefully considered.

Importantly, our model suggests that teachers' practices can shape students' attitudes towards learning genetics. Thus, the teachers should be more aware of how their choices to teach genetics are able to shape students' perceptions and attitudes. Although not intended, teaching can enhance belief in genetic determinism. It is well-known that genetic determinism is a persuasive misconception that can arise from problems in combining classical and molecular genetics models (Gericke & Smith, 2014).

While we need more research on how actual classroom and teaching practices shape student attitudes, we believe that our results already suggest that the approach we have named as *Developmental*, which uses human context in teaching genetics, including complex human traits, and takes genotype-to-phenotype link to centre stage, leads to lower genetic determinism than others and does not compare negatively to other emphases in student attitudes. This link is not surprising as it might make sense to counter genetic deterministic ideas in their own context.

Conclusion

Our study indicates that the student-related factors as well as teacher-related factors explained students' attitudes and beliefs when learning genetics. Most notably, our results suggest that teaching emphasis and materials can lead to more genetic deterministic conceptions in students. We built a model based on simultaneously analysing textbooks, teacher interviews and student questionnaires, thus combining aspects which are usually considered separately and providing a more comprehensive picture on issues affecting genetics teaching and learning. We found clear differences in students' attitudes and beliefs depending whether teaching or textbooks emphasised either more Mendelian or environmental effects in phenotype formation. Unexpectedly, students who had studied more biology, held stronger belief in genetic determinism. This indicates that although the students on average did not hold strong deterministic belief, it turned stronger during their studies. Gender differences were seen across attitudes and beliefs. They were partly expected, such as male students' more positive attitude towards the use of gene technology, and partly unexpected, such as female students' stronger belief in genetic determinism. However, such findings are difficult to explain as gender preferences are often linked to pedagogical contexts and students' own life experiences; indeed, we found larger differences among teachers' emphases than between genders. These student-related preferences would need more detailed study in the future to understand the development of the attitudes and beliefs. Practical implications of our study include strengthening the understanding of genetic and specifically environmental effects on the formation of the phenotype and that teachers should discuss more broadly the societal implications of genetic knowledge and foster critical approaches to obsolescent interpretations of genetics contents and gene technology provided by textbooks. We suggest that teachers' approaches in genetics teaching as well as learning materials need updates to enhance students' genetics literacy.

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Tuomas Aivelo has participated in writing biology textbooks for upper-secondary school biology for eOppi Oy. None of the teachers involved in this study used biology textbooks from eOppi Oy.

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