Why is genetics so hard to learn? Insights from examiner reports for 16- to 18-year-olds in England

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Abstract Genetics forms a major part of A-level biology specifications in the UK for 16- to 18-year-olds. Research has identified several reasons why learning genetics is hard. However, research has not investigated whether examiner reports are useful for identifying difficult genetics concepts for students. This research explored the extent to which examiner reports are a useful tool for inferring student difficulties. A-level biology examiner reports spanning six years were analysed to identify genetics content areas that students have difficulty learning. Follow-up interviews were then conducted with a small number of students and teachers to understand why students find these content areas hard to learn. Teachers and students differed in the genetics content areas they selected as difficult, but students generally agreed with inferences from the analysis of examiner reports.

Understanding genetics is important for both consumers and producers of science. For example, an understanding of genetics allows young people to take informed decisions about contemporary scientific issues such as genetic screening and genetically modified foods (Duncan *et al.*, 2011) and allows biologists to understand fundamental ideas like biological inheritance and evolution. An understanding of genetics plays a substantial role in explaining phenomena in students' lives and facilitates progression onto university courses. Genetics is therefore important to understand. However, studies suggest genetics is difficult to learn (e.g. Duncan and Reiser, 2007; Osman, BouJaoude and Hamdan, 2017).

A-levels are a subject-based UK qualification provided by schools and colleges for students in years 12 and 13, typically for ages 16–18. They are also offered by schools in a number of other countries. A-levels are optional qualifications; however, admission to A-level courses is typically dependent on GCSE grades at age 16. Thus, A-levels are taken by able students who are motivated to study particular subjects. Students generally complete three or four A-levels simultaneously over 2 years.

A-levels are an important and possibly essential qualifications for students seeking to begin further study, university, work or training. Certain A-level qualifications provide students with necessary knowledge and skills to study subjects at undergraduate level. Thus, if students understand A-level content, they are more likely to meet university entry criteria, and this can aid their progression to university.

Genetics comprises a key part of A-level biology specifications in the UK (Department for Education, 2014). Despite the research, such as that cited above, into the difficulties of learning genetics, there is a dearth of published research specifically investigating difficulties in learning A-level genetics.

One potential source of data is examiner reports. Examiner reports provide detailed commentary on students' understanding of different questions in relation to the specification content (Woodger, 2019). Principal examiners write examiner reports, which in the UK are published between August and September each year, after marking has been completed (though the COVID-19 pandemic meant that no A-level examinations were sat in the summers of 2020 and 2021). Examiner reports are designed to be used in conjunction with question papers and mark schemes for a particular examination, with the aim of enhancing student and teacher understanding of the specification content and assessment criteria (Goodenough, 2017). They begin with a commentary on the cohort's approach to each paper, followed by analyses of individual questions (Woodger, 2019). These individual analyses describe whether students, in general, performed well or not on a question and state common mistakes found in answers. Examiner reports are therefore a potentially valuable way to identify content areas students may find difficult. However, the validity of using examiner reports to identify students' difficulties is under-researched. It is possible, for example, that inferences made by principal examiners from looking at students' answers do not actually reflect what students found hard about that question. This research therefore sets out to explore to what extent examiner reports are a useful way of identifying difficult content areas for students.

Why is learning genetics hard?

Over several decades, research has identified, across many age ranges, several reasons why genetics is hard for students to learn (Venville, Gribble and Donovan, 2005; Smith and Knight, 2012). These can be grouped into the five main areas detailed below.

Genetics concepts are abstract

Several studies suggest genetics is difficult because it contains many abstract concepts (i.e. concepts that cannot be seen directly and are beyond our senses). Many abstract concepts exist at the molecular level, such as 'genes' and 'DNA', since this level includes invisible concepts. While it is true that genetics is abstract, abstract concepts are widespread in science (Johnstone, 1991), so this does not on its own explain why genetics is particularly difficult.

Reasoning across levels of representation

Concepts in genetics exist on different levels of representation (macro, micro, molecular and symbolic) (Treagust and Tsui, 2013). For example, learning about inheritance involves ideas at the macroscopic level (e.g. phenotype), microscopic level (e.g. chromosomes), molecular level (e.g. gene mutations) and symbolic level (e.g. Punnett squares). Thus, learners of genetics need to reason between these levels. Different levels of representation are not specific to biology; for example, ideas in chemistry also exist on the macroscopic, molecular and symbolic level. However, the multiple levels of biological organisation (e.g. cells are on one organisational level, tissues are on another organisational level, organs on another still) are specific to biology and add further complexity to genetics.

Reasoning across ontological levels

Duncan and Reiser (2007) suggest that students struggle to integrate knowledge about ontologically distinct entities in genetics, that is, entities that are distinct in their fundamental nature rather than with respect only to what is known about them. A gene is both a unit of information and a section of DNA. Thus, genes exist at both the informational level and the biophysical level, and students need to integrate this knowledge to understand genetics. According to Duncan and Reiser (2007), genetics is a hybrid of ontologically distinct levels.

Connecting concepts

Several studies suggest genetics is hard because students have difficulty connecting different concepts. Students not only have difficulty reasoning across levels of representation, multiple organisational levels and ontological levels, but also may struggle to connect concepts on the same level. Venville and Treagust (2002) found high school students had difficulty connecting different concepts in genetics, such as 'genes' with 'proteins', and 'DNA structure' with 'protein synthesis', because lessons disconnected these concepts. Marbach-Ad (2001) found that students had difficulties connecting concepts such as 'gene' and 'trait' to other concepts such as 'protein', 'DNA' and 'enzymes' and therefore compartmentalise concepts. Marbach-Ad suggests this was a result of focusing on different areas of genetics in different lessons.

Domain-specific vocabulary

Knippels, Waarlo and Boersma (2005) argue that students find genetics difficult because genetics contains a lot of domain-specific vocabulary and terminology. For example, terms such as DNA polymerase, homozygous and codominance tend to be used solely within the context of genetics when students learn biology. Thus, students may not reinforce their understanding of genetics terms in other lessons.

Methods

Overall strategy and sample

The methodology involved two stages. The first stage was examiner-report analysis from the OCR (Oxford, Cambridge and RSA) examination board, one of the three dominant examination boards in the UK, particularly in England. Examiner comments were analysed for genetics questions, and questions were identified where many students struggled. The second stage was face-to-face individual interviews with teachers and students from a South East London mixed comprehensive school. The school was selected because the first author was familiar with it, due to previous employment. Interviews were undertaken to explore whether findings from the examiner-report analysis were valid by giving challenging examination questions to students, to determine whether the students had the same difficulties identified from examiner reports. It could then be determined if examiner reports are an effective tool for identifying student difficulties. The participants were seven A-level biology students from years 12 and 13 (two males and five females) and their two A-level specialist biology teachers, one of whom had been teaching for 10 years, the other for 1 year.

Analysis of OCR examiner reports

A-level biology past papers and corresponding examiner reports for years 1 and 2 of the OCR A-level biology assessment were selected for analysis. This was the examination board used by the school of the interviewed students and teachers. Examiner reports from 2012–2017 were analysed as these related to a new specification that the students were studying for A-level biology. Document analysis of the examination papers first identified questions pertaining to genetics. Based on examiner comments in examiner reports, 13 questions were then identified on which many students had not performed well (see Table 1). For example, comments such as '*Less than 5% of candidates were awarded this mark*' indicated that the question posed substantial difficulties for students. For each such question, the target concept was identified. Student difficulties were inferred based on:

- student exemplar answers mentioned in examiner comments;
- analysing the examination question (as this could indicate why students gave certain answers).

Interviews with students and teachers

Face-to-face individual interviews with teachers and students were used to follow up on the document analysis. Examination questions were selected corresponding to four different areas of difficulty that were identified through the examiner-report analysis. Interviews were designed to last approximately one hour and were audio-recorded. Each interview was transcribed. In interviews, teachers were shown eight past-paper questions from the examiner-report analysis and were asked if they thought students would have difficulties with each question. It could then be determined whether teachers identified difficulties inferred by us from the examiner-report analysis. In addition to this, each year 13 student answered six questions, while year 12 students answered four questions. After answering each question, students were asked to justify their answer. Based on the student's answer, follow-up questions were posed to determine the student's rationale for their answer.

Results

Examiner reports

From analysing the examiner reports, four overarching areas of difficulty were identified (see Table 2). We now discuss eight A-level biology questions that illustrate the difficulties for students, as identified in the examiner reports. (The numbering of these from Question 1 to Question 8 is for the purposes of this article only; the numbers are not necessarily those in the original examination paper and nor is there any significance in the order in which we present them.)

Question 1

> *Many genes code for .... that fold to make enzymes.*

The target answer for Q1 was 'polypeptides'. However, the examiner noted that '*many answers named proteins instead*'. We infer that some students put proteins as they associated proteins with '*genes code for*', since students commonly learn that '*a gene is a section of DNA that codes for a protein*'. For students to correctly answer Q1 they needed to recognise that polypeptides (instead of proteins) fold to make enzymes (which are proteins). Students might also associate the word protein with enzyme.

Question 2

> *The yellow colour in peas is a result of the enzyme that breaks down chlorophyll, which is green.*
>
> *The **Y** allele codes for the production of an enzyme that breaks down chlorophyll.*
> *The **y allele** is a result of a mutation in the **Y** allele.*
> *The **y** allele codes for an inactive form of this enzyme.*
>
> *Outline how the **Y** allele codes for the production of this enzyme **and** explain why the **y** allele codes for an enzyme with a different primary structure.*

The target concepts for students in Q2 were transcription and translation. The examiner remarked that students did not use certain terms in the correct context, for example '*using bases in the context of amino acids*'. We infer that students have difficulty using correct terms because they do not understand how particular concepts are related. For example, students needed to understand that a base sequence *codes for* a particular amino acid rather than, as some students stated, bases coding for the *production* of amino acids. At the same time, it is possible that some of the difficulties experienced by students, with respect to this and other questions, is due to their wording.

Question 3 (continued from Q2)

> *With reference to the proteins coded for by the seed colour gene explain why the **y** allele is recessive.*

The target concept for Q3 was recessive alleles. The examiner commented that '*Many candidates thought that merely being mutated or less frequent in a population makes an allele recessive*'. We infer that these students associated the supposed strength of dominant alleles with these alleles becoming more common in a population, compared to recessive alleles. Thus, students had difficulty learning the scientific meaning of '*dominance*', in part because of their understanding of the word in everyday language.

Table 1 Analysis of examiner reports. Questions marked with * were used in the interviews

Examination paper and question	Target concept	Examiner comments
*F215 Control, genomes and environment, June 2016, Q2(a)	Polypeptide structure	Many answers named proteins instead of polypeptides for the second [marking point], which gained no credit.
*F215 Control, genomes and environment, June 2015, Q4a(i)	Geographical barrier	This question was answered well, but sometimes candidates confused their answer with types of speciation. Allopatric was a common mistake, as was geological as opposed to geographical.
*Q4a(ii)	Genetic drift	The majority of candidates answered this question correctly. The most common error was to name it as a mutation.
*H420/02 Biological diversity, June 2017, Q17(c)(i)	Transcription/Translation	using bases in the context of amino acids stating that bases code for the *production* of amino acids and stating that the amino acid sequence *codes for* the primary structure of a protein.
*H420/02 Biological diversity, June 2017, Q17(c)(ii)	Recessive alleles	Many candidates thought that merely being mutated or less frequent in a population makes an allele recessive.
H420/03 Unified biology, June 2017, Q3(a)(i)	Anatomical adaptation	'*physiological*' was the most common mistake.
H420/03 Unified biology, June 2017, Q3(a)(ii)	Structural genes	Students wrote about a 'mutation in a gene for striped fur' rather than naming the structural gene as being responsible for fur colour or producing a coloured pigment.
H420/03 Unified biology, June 2017, Q3(a)(ii)	Regulatory genes	role of regulatory genes in controlling gene expression is an area which was poorly understood by the majority of candidates.
H420/03 Unified biology, June 2017, Q3(a)(ii)	Identification of the correct selection pressure for stripes being better adaptation for hunting due to camouflage	Only 50% of candidates identified this.
H420/03 Unified biology, June 2017, Q3(b)	Correctly calculate the values of p and q and substitute them into the equation	Most candidates failed to give the correct final result but managed to score at least one of the three marks available. A high proportion of candidates are able to correctly calculate the value of p and q but then got lost trying to substitute them into the equation. A few candidates calculated $2pq$ correctly but did not go on to calculate the percentage, while some others followed the calculation to the end but did not round up the result to one significant figure.
F215 Control, genomes and environment, June 2014, Q6(b)	Calculating Hardy–Weinberg equation	Candidates still struggle with the application of the Hardy–Weinberg principle, and few candidates gained any marks. Often students used BB, Bb and bb instead of the p and q, and an obvious misunderstanding was not recognising the need to start with q^2. Many candidates calculated p instead of q and many also wrote a p answer above the value 1, which demonstrated a lack of understanding that $p + q = 1$.
*F212 Molecules, biodiversity, food and health, June 2015, Q5(c)	Intraspecific variation	Four marks are usually awarded for this question. The most common incorrect response was where 'intraspecific' should have been. Many candidates wrote '*interspecific*', '*continuous*' or left it blank. A minority of candidates wrote '*speciation*' or '*characteristics*' in the last space.
*F215 Control, genomes and environment, June 2012, Q1(b)(i)	Selective breeding	Many candidates found this question difficult however, with evolution, natural selection and speciation appearing in both sections and artificial selection being given wrongly for part (ii).
*Q1(b)(ii)	Mutation	Many candidates found this question difficult however, with evolution, natural selection and speciation appearing in both sections and artificial selection being given wrongly for part (ii).

Table 2 Reasons for genetics being difficult to learn as inferred from examiners' comments in reports from OCR A-level biology examinations from 2012 to 2017; the 'Description of difficulty' column gives a short explanation of why we suspect the difficulty exists

Area of difficulty	Example of where difficulty has led to an error	Description of difficulty
Difficulty using the correct term	'Bases code for the *production* of amino acids.' 'Amino acid sequence *codes for* the primary structure of a protein.'	Incorrect term is used to describe processes. The description is therefore inaccurate.
Everyday language has a different meaning to the scientific language	Recessive alleles are mutated or less frequent in a population. A dominant allele is understood by some students as being more powerful and thus more frequent.	'Dominant' in everyday language is understood as meaning 'overpowering'. This understanding interferes with learning its meaning in genetics.
Difficulty disconnecting terms learnt in association	When asked to state *random* change in allele frequency, 'mutation' is given as an answer.	'Mutation' and 'random' are frequently learnt in association, as mutations are defined as random changes in the DNA sequence.
Confusing similarly spelt words (paronyms)	'interspecific' used rather than 'intraspecific'.	Similar spellings of these words can make it difficult to remember the difference between the two terms.

Question 4

*When a new road system was constructed, it split a population of rare snail species into three smaller populations **A**, **B** and **C**. As a result, each of these populations became reproductively isolated. Name the type of isolating mechanism that prevents interbreeding between these snail populations.*

The target answer was 'geographical barrier'. The examiner stated: '*candidates confused their answer with types of speciation. Allopatric was a common mistake*'. We infer that some students associated the term '*isolating*' with allopatric speciation, where populations become isolated due to a geographical barrier and evolve to become different species. A geographical barrier can be described as an isolating *mechanism*, whereas allopatric speciation can be described as an isolating *process*. Students needed to understand the importance of the '*new road system*' mentioned in the question as an isolating mechanism and geographical barrier to answer Q4 correctly.

Question 5 (continued from Q4)

*The habitat of these snail populations did not change over the ten years. State the term used to describe the **random** changes in allele frequency in a snail population.*

The target answer for Q5 was 'genetic drift'. The examiners stated that the '*most common error was to name it as a mutation*'. We infer that students associate '*random*' (which was in bold in the question) with 'mutations', as mutations are often described as random changes in the base sequence of DNA.

Question 6

Variation between members of the same species is known as .... variation.

The target answer for Q6 was 'intraspecific'. The examiner stated: '*Many candidates wrote interspecific*'. We infer that some students were unsure of the difference between intraspecific and interspecific variation, as they are spelt and sound quite similar.

Question 7

Name the process that (i) has given rise to the modern domestic cat from its wild ancestor.

The target answer for Q7 was 'selective breeding'. We infer that some students failed to recognise the significance of the word '*domestic*'. Some students saw the modern domestic cat as a product of speciation from its wild ancestor. Candidates focused on '*wild ancestor*' and immediately thought about speciation/natural selection, disregarding '*domestic*'.

Question 8 (continued from Q7)

Name the process that (ii) has given rise to coat colour variation in cats.

The target answer for Q8 was 'mutation'. The examiner stated that students found this question difficult with '*artificial selection being given wrongly*'. We infer that students associated the word '*variation*' with selective breeding, which may involve a human desire to have breeds with particular coat colours.

Interviews

Teacher interviews

Two teachers were interviewed in order to determine whether they identified the difficulties we inferred (Table 3) from the examiner reports.

For Q1, teacher A said *'Most mark schemes will accept polypeptide or protein*'. However, teacher B suggested

Table 3 Summary of students' rationales for their answers to difficult examination questions in interviews

Examination question given to students in interviews	Target concept	Difficulty inferred by the authors from examiner comments	Summary of students' rationales for their answer
1	Polypeptides	Difficulty disconnecting terms learnt in association	Most students answered '*proteins*' because they had learnt genes or enzymes in association with proteins, e.g. '*genes code for proteins*'.
2	Translation	Difficulty using the correct term	Several students used incorrect terms to describe translation, as they struggled to use precise language.
3	Recessive alleles	Everyday language has a different meaning to the scientific language – we inferred that many examination candidates thought 'dominant' (in the context of alleles) meant more powerful and would thus be more frequent compared to recessive alleles	Responses to this question indicated that students perceived recessive alleles to be less frequent if other alleles are present.
4	Geographical barriers	Difficulty disconnecting terms learnt in association	Some students answered this incorrectly, since the term 'isolating' appeared in the question.
5	Genetic drift	Difficulty disconnecting terms learnt in association	Most students thought '*mutation*' was correct as the question stated 'random', and they had learnt 'random' and 'mutations' in association.
6	Intraspecific/ interspecific variation	Confusing similarly spelt words (paronyms)	All students answered this correctly.
7	Selective breeding	Difficulty disconnecting terms learnt in association	Some students answered '*evolution*' as they had learnt evolution in association with the terms 'ancestor' and 'process'.
8	Mutations	Difficulty disconnecting terms learnt in association	Most students associated terms in the questions such as 'variation' and 'colour' with the terms 'selective breeding' and 'natural selection'.

that students would struggle to connect '*DNA*', '*genes*', '*polypeptides*' and '*enzymes*' with each other, as these ideas are '*taught separately*'.

For Q2, teacher A claimed that '*students lack stock phrases*' when describing the role of tRNA, such as '*tRNA carries an amino acid*', and that students would struggle to respond to 'command words' in the question. Teacher B thought students might not relate Punnett squares to DNA as '*each idea is presented differently*'.

For Q3, teacher A suggested students are '*not able to convey what recessive means in written form*'. Teacher B, however, suggested that some students perceive dominant as being more powerful because of its meaning in everyday language.

For Q4, teacher A thought that students may answer '*allopatric speciation*', given that the word '*isolating*' was in the question.

For Q5, teacher A suspected students might answer '*directional selection*' since '*allele frequency*' was stated in the question. Teacher B suggested that the question assessed students' '*ability to recall key definitions*'.

For Q6, teacher A suggested that students would not have difficulty correctly answering this question and did not think the similar spelling of '*interspecific*' and '*intraspecific*' would be challenging for students; rather, they thought it would only pose problems for students '*who simply hadn't learnt the term*'. Teacher B thought students might struggle with this question if they did not understand the prefixes 'intra' and 'inter'. Teacher B also thought students may confuse 'types' of variation (e.g. intraspecific and interspecific) with 'causes' of variation (e.g. genetic and environmental).

For Q7, teacher A suggested that students '*often give partial or incomplete answers when having to explain natural selection or evolution*'. Teacher B claimed that a potential problem is '*thinking about processes at different scales*' (e.g. macroscopic and microscopic).

For Q8, teacher A thought that students can confuse selective breeding and natural selection, and teacher B thought that '*reasoning between the macro and micro scale may be a difficulty*'.

Student interviews

Interviews with students aimed to explore whether students had the same difficulties with questions that we inferred from the examiner reports. Table 3 shows that the most frequent difficulty inferred from the examiner-report analysis was '*Difficulty disconnecting terms learnt in association*'. This could be due to students being prompted by particular words in examination questions. For example, in Q1, students needed to realise that '*polypeptides fold to make enzymes*'. Many students in interviews focused on the first part of the sentence that stated '*genes code for*' or the word '*enzyme*'. Students associated the words '*genes*', '*code*' and '*protein*', causing them to answer '*protein*'. The word '*enzymes*' at the end of this sentence was critical for students if they were correctly to answer '*polypeptides*'. Student A had associated genes and proteins and initially answered '*proteins*' because they remembered the definition of genes being '*they code for proteins*' but then correctly stated '*polypeptides*'. Student G answered '*I put proteins because enzymes are proteins*', having presumably learnt to associate '*proteins*' and '*enzymes*'. Student D also answered '*proteins*' as '*enzymes*' was in the question, and said '*enzymes are proteins*'.

For Q2, we concluded that students lacked precision in the terms they used. For example, student A had difficulty using accurate language to describe transcription and stated that a '*gene gets mimicked into the mRNA*'. Students were required to write a longer, more descriptive answer compared to other examination questions. Bases do not code for the *production* of amino acids; instead, bases code for amino acids. The amino acid sequence does not 'code' as some students claimed; instead, the '*amino acid sequence determines the primary structure of a protein*' or '*the DNA sequence codes for the primary structure of a protein*'.

For Q4, we inferred that students had learnt '*isolating*' in association with '*allopatric speciation*', as a common mistake was to answer '*allopatric speciation*'.

Considering Q5, students frequently learn that a mutation is a random change in a DNA sequence. The words '*random*' and '*change*' featured in the question, causing students to connect these words with mutation. Furthermore, '*random*' was in bold in the question, so students were prompted to focus on '*random*' for their answer. Indeed, when interviewed, several students gave incorrect answers because they associated '*random*' and '*change*' with mutations.

Students interviewed did not find Q6 difficult, as all answered it correctly. This could be because students were provided with a definition of intraspecific variation in this question ('*Variation between members of the same species*'), so only had to remember the difference between interspecific and intraspecific variation.

For several questions, students had difficulties because of particular words in the questions. For example, Q7 included two words that students had learnt in association with evolution. One word was '*process*' and the other was '*ancestor*'. When students learn evolution, they learn that evolution is a process where species change over time; they are taught that new species may diverge or evolve from a common ancestor. Several students referred to '*process*' in their explanations for their answers.

For Q8, students had learnt about natural selection in association with '*process*' and '*variation*', words that featured in the question. Students learn about the process of natural selection, occurring over long periods. Students also learn that natural selection produces different or a varied species. For example, student G had associated '*colour variation*' with light and dark peppered moths as an example of natural selection. This explains why students associated the word '*variation*' with '*natural selection*' instead of the correct answer '*mutation*'.

Discussion: Are examiner reports valid tools for inferring student difficulties?

Our analysis of examiner reports identified a number of subtle reasons, often grounded in language, that help explain why some students have difficulty learning genetics concepts. For example, according to an examiner report, some students stated that an amino acid sequence *codes for* the primary structure of a protein, rather than that the amino acid sequence *determines* the primary structure of a protein. During the student interviews several students struggled to use certain terms correctly (see Table 3). This suggests that focusing on language in science is important for improving students' learning of science (Sutton, 1993), since the technical and non-technical words used in science pose difficulties for students (Wellington and Osborne, 2001).

Analysis of the examiner reports revealed that some students confuse the everyday meaning of certain words with the scientific meaning; for example, some students thought recessive alleles were necessarily less frequent than dominant alleles in a population. Presumably such students perceive allelic dominance to mean that dominant alleles are more powerful and thus more frequent. Indeed, in the interviews, some students suggested that recessive alleles are less frequent in populations. 'Dominant' is an example of a polysemous word (a word with multiple meanings). Polysemous words can be challenging for teachers and students because new connections must be established between the polysemous word and the scientific meaning (Johnstone, 1991; Strömdahl, 2012), and everyday meanings can be very robust (i.e. resistant to change). Indeed, undergraduates connect increasing allele frequency in a population with dominance (Abraham, Perez and Price, 2014).

Another finding from this study is that particular terms *learnt* appropriately in association can sometimes be *used* in association incorrectly when answering questions. From analysing examiner comments, we hypothesised that students may struggle to disconnect terms learnt in association (see Table 2). This hypothesis received confirmation during the interviews as several students incorrectly answered three questions because they had learnt certain terms in association. While we accept that forming connections between concepts in genetics is crucial to understanding the subject, findings here indicate that some terms learnt in association can be difficult to disconnect, and can therefore lead to misconceptions. It is important that students do not merely rote-learn definitions, but are helped to understand the concepts that are being defined (see Devetak and Vogrinc, 2013).

Our analysis of examiner reports revealed that some students confused similarly spelt words that have different meanings (paronyms), such as 'intraspecific' and 'interspecific'. Other research has found students confused the paronyms 'homologue' and 'homologous' (Bahar, Johnstone and Hansell, 1999). However, in our study students in interviews did not confuse 'intraspecific' and 'interspecific'. Teachers can help students distinguish paronyms by breaking them up into their constituent parts and helping students appreciate what part of speech they are (e.g. 'homologue' is a noun while 'homologous' is an adjective).

Conclusion

This research aimed to explore whether examiner reports could be used as a research resource to identify student difficulties when learning genetics. The review of literature indicated that, although genetics is difficult to learn (Duncan and Reiser, 2007; Osman *et al.*, 2017), A-level examiner reports as a tool for inferring student difficulties were under-researched. Examiner reports and the corresponding examination questions were analysed. From the errors identified in the examiner reports, we inferred student difficulties in genetics. Interviews were then conducted with two teachers and seven students to confirm or reject inferences made.

We conclude that examiner reports are effective tools for inferring student difficulties in genetics because the inferences we made using examiner-report analyses regarding student difficulties were largely confirmed by students' interview responses. Through analysing examiner reports, we inferred that students have difficulty with:

- selecting correct words;
- disconnecting terms learnt in association;
- learning scientific terms with a different everyday meaning;
- distinguishing similarly spelt words.

Several students also stated they had difficulty visualising particular genetics concepts, suggesting that the abstract nature of genetics poses learning difficulties. Moreover, teachers claimed that students struggled to connect ideas from different topics such as 'Punnett squares' and 'DNA', perhaps because textbooks compartmentalise these topics.

Finally, this research raises broader questions about the difficulties that students have when learning science. For a start, are our conclusions specific to genetics or applicable to other topics, both in biology and in the other sciences? We analysed OCR examiner reports; do our findings hold for other examination boards, and do they hold for GCSE examinations as well as for A-level examinations? Further research on the validity of examiner reports for identifying student difficulties will be valuable for improving learning in the science classroom.

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