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"It's the X and Y Thing": Cross-sectional and Longitudinal Changes in Children's Understanding of Genes

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Abstract Studies from different theoretical traditions investigating children's inheritance and genetics concepts have adopted a cross-sectional method. This paper is the first to examine both cross-sectional and longitudinal changes in children's basic genetic concepts. It forms part of a larger investigation into the development of intuitive inheritance and genetics concepts in childhood. Four age cohorts (4–5 years, 7–8 years, 10–11 years, 14–15 years) were interviewed individually at two measurement occasions (T1, N=182; T2, N=164) separated by a 1-year interval. Cross-sectional analyses revealed an increase in children's knowledge of genetics by 10 years. Between 10 and 14 years, there were fewer changes in the content of children's knowledge, especially at the level of scientific genetic understanding. There was little evidence of longitudinal changes over the 1-year period. Overall, children may hold an understanding of genetics that is tied to knowledge of inheritance within families. This may pose challenges for acquiring more abstract and formal concepts of genes.

Keywords Adolescent misconceptions · Conceptual development · Biology learning · Inheritance learning · Genetics learning

Introduction

In recent years, there has been a significant increase in studies on children and adolescents' conceptions of genetics and the basics of biological inheritance. This work has been driven by two research foci. On the one hand, developmental psychologists are concerned with the cognitive origins of naive inheritance concepts and the age at which children are able to reason about inheritance biologically (e.g., Astuti et al. 2004; Atran 1998; Wellman and Gelman 1992; Wellman and Inagaki 1997; Williams and Affleck 1999; Williams and Smith 2004, 2005; Williams and Tolmie 2000). This has led developmental psychologists to

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focus their research efforts at younger children (4–7 years). On the other hand, research in science education has explored genetic concepts among older children and adolescents because of demonstrable difficulties in learning formal genetics (e.g., Engel-Clough and Wood-Robinson 1985; Evans 2000; Finkel 1996; Furnham 1992; Kargbo et al. 1980; Lawson and Thompson 1988; Lewis et al. 2000a, 2000b, 2000c; Lewis and Kattmann 2004; Longden 1982; Slack and Stewart 1990; Stewart 1982; Thomas 2000; Wood-Robinson 1994). Studies in science education tend to focus on adolescents in secondary school and to a far lesser extent on children in the late primary school years (except Deadman and Kelly 1978; Venville et al. 2005).

The consequence of these various research endeavours is a body of developmental literature that is piecemeal. There is a significant research gap in how children in late primary and early secondary school (7–12 years) understand genetics. Furthermore, the predominant use of cross-sectional design methods means we know very little about longitudinal changes in knowledge of genetics. Indeed, there have been calls for longitudinal research to investigate developmental trends in conceptual understanding of biology and science (Black and Lucas 1993; Reiss and Tunnicliffe 1999; White and Arzi 2005) particularly, inheritance and genetics (Richards 2000). The purpose of this study is two-fold. Firstly, to describe the content of children's knowledge of genetics at different ages. Secondly, to examine longitudinal changes over a one-year period in 4 to 14 year-olds' understanding of the role of genes in inheritance. This study is part of a larger research project examining the development of intuitive inheritance and genetics concepts in childhood and adolescence (Smith and Williams 2004; Williams and Smith 2004, 2005, 2006).

There are important theoretical and applied reasons why the acquisition and content of genetic concepts in children deserves attention. Firstly, children have experience of kinship and family resemblance from a young age (Richards 1996) and kinship terms are among their first words (Hirschfeld 1989), so this is a set of phenomena that may be conceptualised early in development. Secondly, among older children and adolescents there is evidence of conceptual difficulties in learning the science of genetics (Thomas 2000) that may have its origins earlier in development. By examining how knowledge of inheritance and genetics develops in childhood, academics and teachers have an opportunity to devise age-appropriate educational materials in an effort to enhance understanding. The following sections outline existing research findings on the development of inheritance and genetic concepts.

Several researchers have investigated the onset of inheritance and kinship concepts in young children. This body of work has shown that pre-school children expect offspring to resemble their parents, especially on physical traits (Gelman and Wellman 1991; Springer 1992; Weissman and Kalish 1999). Children of this age acknowledge that babies share more physical features with kin than non-kin (Springer 1992, 1996), they have knowledge that babies come from mothers' bellies (Berstein and Cowan 1975; Springer 1995) and conceptualise inheritance as involving an internal process of material transfer from mother to offspring (Springer and Keil 1991). However, young children tend to show less knowledge of biological inheritance (Solomon et al. 1996). Indeed, some researchers argue that children's conceptions of inheritance are derived from prior understanding of kinship and social relationships (Carey 1985; Da Rosa and Solomon, 1998; Richards 1996, 2000). According to this view, young children may have a difficulty in shifting from a social to a biological conception of inheritance.

By 7 years, children are beginning to develop a more physiological understanding of inheritance. They understand birth to be a causal mechanism that selectively mediates the inheritance of physical features and not the acquisition of beliefs (Solomon et al. 1996). However, there is very little evidence of genetic concepts. Indeed, the development of basic genetic concepts in middle childhood (7–12 years) is under-researched. An exception is a recent study by Venville et al. (2005) who investigated 9–15 year-olds' knowledge of genetics. Although many children in this age group had heard of the term 'genes,' there was little evidence of understanding the structural and functional aspects of genes. Instead, older children's concepts of genetics seemed to be embedded within their understanding of kinship relationships.

Studies in science education, focusing mainly on secondary school students (12+ years), have highlighted the conceptual difficulty of learning about genetics (Deadman and Kelly 1978; Kargbo et al. 1980; Lewis et al. 1997, 2000a). Lewis et al. (1997, 2000a), in a large investigation of students' understanding of genetics, found that 96% of their sample aged 14–16 years had heard of the term 'gene.' Wood-Robinson (1994) reports that 14–16 year-olds are likely to use the term 'gene' even before exposure to formal school teaching about genetics. Despite this, few students develop a conception of a gene that is consistent with today's genetic information age (Lewis and Kattmann 2004; Venville and Treagust 1998). Research suggests that most adolescents view a gene as being a passive entity that influences characteristics (Venville and Treagust 1998) or a trait-bearing particle (Lewis and Kattmann 2004) as opposed to a chemical that codes for the production of proteins. In Lewis et al. (2000a), 73% of students indicated that genes were important because they determined characteristics, with the majority mentioning physical traits. However, few students were aware of the location of genes. Only a half of 14–16 year-olds said genes were found in cells. Furthermore, there seemed to be little awareness of the relationship between genes and chromosomes with both terms often used interchangeably. Lewis et al. (2000a) concluded that with such a limited knowledge of genetics it is difficult to see how students would develop a scientific understanding of biological inheritance.

The majority of these cross-sectional studies focus on a narrow age range of children and only examine the content of children's conceptions at one moment in time. This makes it difficult to establish (a) what children know about genetics at different points in development and (b) whether there may be sensitive periods in which children may optimally develop knowledge and learn about genetics. The main objective of this study was to provide a more comprehensive examination of the development and content of basic genetic concepts in childhood. A broad age range of children participated in the study (4–5, 7–8, 10–11 and 14–15 years) in order to bridge the gap between psychological and science education research. Furthermore, these are key ages at which developmental changes in inheritance concepts have been identified from previous cross-sectional work. We used a one-year longitudinal design methodology (White and Arzi 2005) to consider how ideas about genetics might change over a specified period of time. This study probed different aspects of children's intuitive genetic concepts in order to elucidate the content of their knowledge.

Materials and Methods

Participants

The data were collected on a sample of children and adolescents at two interview occasions separated by a 1-year interval (see Table 1).

In the first phase of data collection (conducted in 2003), 182 children from four age cohorts (4, 7, 10 and 14 years) were interviewed. One year later (±14 days), 90.1% (N=164) of the

Table 1 Participant information

	Time 1	Time 2
Young childhood cohort		
Age in years	4–5	5–6
Mean age in years	4.5	5.6
Males (n)	24	23
Females (n)	22	18
Middle childhood cohort		
Age in years	7–8	8–9
Mean age in years	6.9	8.1
Males (n)	21	20
Females (n)	24	21
Older childhood cohort		
Age in years	10–11	11–12
Mean age in years	10.8	11.7
Males (n)	15	14
Females (n)	30	29
Adolescent cohort		
Age in years	14–15	15–16
Mean age in years	14.1	15.3
Males (n)	20	20
Females (n)	26	20
Total (n)	182	164
Resampling rate (%)		90.1

original sample were interviewed. Children attended schools in three different locales and each school was categorised as belonging to either a low, mid or high socio-economic group based on free school meal entitlement figures (Scotland's Census: 2001 Population Report, General Register Office for Scotland 2002; Scottish Executive 2003). Written parental permission was sought prior to the interviews for participation in both time phases of the project.

Reports from the teachers and students themselves indicated that none of the 4 and 7 year-olds had been taught about inheritance or genetics formally in school. Although the majority of pupils in the 10 year-old cohort were aware of the term 'gene,' only a third of them indicated they had been formally introduced to the concept of genes as part of sex education outlined in the Scottish Executive's Health Education 5–14 National Curriculum (Scottish Executive 2000b). All pupils in the 14 year-old cohort received formal education on biological inheritance in the early secondary school years as part of the Environmental Studies 5–14 National Curriculum Guidelines (Scottish Executive 2000a). This included an introduction to the concept of genes, the physical basis of inheritance and its links to reproduction. However, no pupil in the adolescent cohort had yet received formal input about genetics at a cellular level, as part of Standard Grade Biology.

Study Design and Context

This paper describes a set of findings drawn from a larger scale longitudinal project examining the development of inheritance concepts during childhood and adolescence. The project took the form of semi-structured interviews and included six tasks that were designed to elicit judgements and explanations about different aspects of inheritance understanding (see Williams and Smith 2006). This paper describes the sixth interview task that examined children's awareness and knowledge of genetics. This task was designed to elicit children's own ideas and understanding about genetics rather than calculating the frequency of or assessing how closely their ideas approximate to scientifically accurate knowledge. A series of both open-ended and fixed choice questions (see Appendix), drawn from naïve biology research (Springer 1995) and science education studies (Lewis et al. 2000a; Ramorogo and Wood-Robinson 1995) were used. Although the use of open-ended questions may have been difficult for some of the younger participants, the aim was to document children's own reasoning about genetics within the context of a larger investigation of inheritance understanding, without constraining the responses given.

Questions and Procedure

Children were asked a series of 15 questions to probe conceptual understanding of basic genetics (see Appendix). Question 1, aimed at the younger children, asked about the location of pre-natal growth. Previous research has shown that when children (4–7 years) have knowledge of certain facts (e.g., location of pre-natal growth), they begin to draw more appropriate inferences about inheritance processes (Springer 1995). Question 2 explored children's ideas about the origin of gender (Ramorogo and Wood-Robinson 1995). The remaining questions, adapted from previously published work, explored children's conceptual understanding of genes (Lewis et al. 2000a; Ramorogo and Wood-Robinson 1995). The questions explored children's awareness of genes (question 3), an understanding of genes (question 4), knowledge of gene function (question 5), location (question 6), origin (question 7) and malleability (question 8). Children were asked whether genes are important (questions 9 and 10) and for their understanding of the terms 'genetic code' and 'human genome' (Lewis et al. 2000a). Finally, children were asked where they had learnt about genes (question 15).

Participants were interviewed individually in their nursery or school. The questions were presented to children in a fixed-order sequence. The interview was designed such that every participant was asked the first three questions. However, if a respondent indicated that they had never heard of 'genes,' the interview was concluded after question 3 because the respondent would be unable to answer further questions about the nature of genes. Responses were audio-recorded and transcribed for subsequent analysis.

Coding

To examine children's open-ended responses, we used content analysis to create coding schemes based on participants' own responses (see Appendix). The content analytic method has the advantage of combining what are traditionally thought to be two antithetical approaches to analysis: qualitative and quantitative techniques (see Krippendorff 1980; Weber 1985). Responses to each question were allocated a code and percentage counts were made on the frequency of types of answers. In order to validate the coding scheme, a sample of responses was given to an independent rater. A reliability check on 20% of the data indicated overall a 90% agreement on how explanations were coded.

Results

The analysis will consider cross-sectional and longitudinal trends in children's basic genetic concepts. Cross-sectional comparisons of interviews at Time 1 used chi-square to examine patterns of responding for each question for each age group (4, 7, 10 and 14 years)

Table 2 Percentage response to the question *"Where do babies grow before they are born?"*

Coding categories	Percentage response							
	Young		Middle		Older		Adolescent	
	T1	T2	T1	T2	T1	T2	T1	T2
Don't know/no response	60.9	46.3	42.2	53.7	24.4	27.9	19.6	22.5
Stomach/belly	39.1	53.7	57.8	46.3	31.1	34.9	21.7	15.0
Womb/uterus	–	–	–	–	44.4	37.2	58.7	62.5

T1 and T2 denote time phases

separately. This method of analysis demonstrates whether responding was even across response categories for an age group or skewed towards a particular response type. Longitudinal trends in children's responses were then investigated for each age cohort separately using chi-square to reveal associations between Time 1 and Time 2. Consistent with content analytic techniques (Weber 1985), percentages of response types are also reported in addition to significant statistical trends. Although each participant was asked the same set of questions, some participants indicated a lack of awareness of genes. These participants were not asked subsequent questions about genes. For this reason, the percentages presented in the tables relate only to the proportion of respondents who indicated they were aware of genes. In addition to reporting quantitative data on children's conceptual understanding of genetics, selected quotes are used to illustrate the findings. The results will be reviewed for each question in turn.

Findings from the *location of pre-natal growth* question (Table 2) revealed a statistically significant cross-sectional trend in knowledge of where babies grow prior to birth for the adolescents only (χ^2 (2)=15.65, p<.001). The 14 year-olds tended to report that babies grow inside the womb or uterus. The longitudinal analysis showed no statistically significant changes in knowledge for any age cohort.

There were statistically significant cross-sectional trends in responding for each age group and explanations of the *origin of gender* (4 years: χ^2 (3)=75.57 p<.001; 7 years: χ^2 (4)=80.89 p<.001; 10 years: χ^2 (3)=50.20, p<.001; 14 years: χ^2 (3)=50.52, p<.001). Few 4 and 7 year-olds were able to give an explanation for the *origin of gender* (Table 3). When they could offer explanations, they were not usually biological ones; "because sometimes the mummy wants it to be a boy or a girl" (SJ, aged 4). The 10 year-olds also had difficulty

Table 3 Percentage response to *"Why are some babies born boys and others are born girls?"*

Coding categories	Percentage response							
	Young		Middle		Older		Adolescent	
	T1	T2	T1	T2	T1	T2	T1	T2
Don't know/no response	80.4	82.9	73.3	82.9	68.9	76.7	67.4	52.5
External	4.3	4.9	6.7	7.3	2.2	2.3	2.2	–
Birth	6.5	12.2	11.1	4.9	–	2.3	–	2.5
Reference to parents	8.7	–	6.7	4.9	–	2.3	–	5.0
Sperm/eggs	–	–	2.2	–	6.7	7.0	4.3	7.5
Genes/chromosomes	–	–	–	–	22.2	9.3	26.1	32.5

T1 and T2 denote time phases

understanding what determines gender. A higher percentage of 14 year-olds than the 10 year-olds reported that genes or chromosomes determine gender. However, even at these ages, their responses lacked any detailed understanding of the mechanism; "I don't know what controls it but it's something to do with that X and Y chromosome thing" (CB, aged 10) or were inaccurate; "something to do with Y and X chromosomes; one is a bigger influence I think" (RS, aged 14). The longitudinal analysis for each age cohort showed no statistically significant changes in explanations of the origin of gender.

Findings from the *awareness of genes* question showed statistically significant response trends in awareness of genes for each age (4 years: χ^2 (1)=38.35, p<.001; 7 years: χ^2 (2)= 78.40, p<.001; 10 years: χ^2 (1)=18.69, p<.001; 14 years: χ^2 (2)=69.70, p<.001). Most children under the age of 10 years had never heard of genes whereas older children showed increased awareness. Longitudinal analysis failed to reveal any statistically significant changes in awareness of genes for any age group. However, interestingly, there were trends in the data suggesting improvements in awareness amongst 7 and 10 year-olds between Time 1 and 2. By contrast, the number of older children indicating they had heard of genes decreased slightly over the year. For the remainder of the analyses, 7 year-olds were excluded due to insufficient numbers of children responding.

When asked to explain "*what are genes?*" (Table 4), a statistically significant cross-sectional response trend was found for the 14 year-olds (χ^2 (5)=15.83, p<.01). The most common response amongst the 14 year-olds was that genes were 'parts of the mum and dad'. For example, "parts of the mum and dad that pass onto the baby" (GC, aged 14). Statements that related genes to characteristics were also common. There were no statistically significant longitudinal changes for any age group. However, some interesting trends are worthy of elaboration. After one year, the percentage of the older childhood (11 years) explaining genes as part of the mum and dad increased to 59.4%. The adolescent cohort was less likely to give this response after a year, with a greater number of 15 year-olds mentioning DNA. The cross-sectional and longitudinal analyses indicated persistent confusion across both time phases amongst the older children about the difference between genes and chromosomes. For example, "you get 32 from your mum and 32 from your dad and it makes up your whole body" (LR, aged 10) and "I think there's 24 in your body and you take 12 away" (RL, aged 11). One 14 year-old pupil said that genes "decide if it's going to be a boy or a girl" (LB, aged 14). Only one child stated explicitly that genes were "the things that are inside DNA" (GC, aged 14).

In response to the question *"what do genes do?"* a variety of responses were given. A statistically significant cross-sectional response trend in explanations of what genes do was found for the 14 year-olds only (χ^2 (5)=24.96, p<.001). The most frequent answer (45.2%)

Table 4 Percentage response to *"What are genes?"*

Coding categories	Percentage response							
	Young		Middle		Older		Adolescent	
	T1	T2	T1	T2	T1	T2	T1	T2
Don't know/no response	–	–	100	50.0	18.9	6.3	23.8	28.6
Parts inside the body	–	–	–	25.0	13.5	12.5	14.3	14.3
Parts of the mum and dad	–	–	–	–	27.0	59.4	38.1	28.6
Traits	–	–	–	25.0	27.0	12.5	19.0	17.1
DNA	–	–	–	–	13.5	9.4	4.8	11.4

T1 and T2 denote time phases

Table 5 Percentage response to *"What do genes do?"*

Coding categories	Percentage response							
	Young		Middle		Older		Adolescent	
	T1	T2	T1	T2	T1	T2	T1	T2
Don't know/no response	–	–	100	50.0	32.4	31.3	23.8	20.0
Produce a baby	–	–	–	50.0	12.5		16.7	8.6
Similarity to parents	–	–	–	–	16.2	6.3	7.1	5.7
Individual differences	–	–	–	–	2.7	–	7.1	–
Determine characteristics	–	–	–	–	29.7	50.0	45.2	65.7

T1 and T2 denote time phases

amongst the 14 year-olds (and the 10 year-olds: 29.7%) was that genes determine characteristics; "they make up your physical features" (RB, aged 15). However, almost a quarter (23.8%) of 14 year-olds (and 32.4% of 10 year-olds) was not able to respond to this question. There were no statistically significant longitudinal changes found in children's explanations of what genes do.

The majority of older children's responses at both time phases were about genes determining physical traits. For example, "they control your hair colour and skin colour" (NG, aged 15) and "it's like whether you have blue eyes or blonde hair, if you are tall or small" (JF, aged 14). Only rarely did children see a relationship between genes and personality traits: "genes give you your personality and what you look like" (JM, aged 10), "just determine your personality and the way you are" (JJ, aged 14). Respondents were even less likely to say genes determine illnesses or disabilities. At Time 1, only one 10 year-old mentioned general health in relation to genes; "to keep from getting ill" (AB, aged 10). By Time 2, these responses were still infrequent but were more elaborated:

> they sometimes predict family diseases. If your mum and dad has got good eyesight you can't catch it, but if your mum and dad hasn't got good eyesight and you get more of your mum's genes, you can't catch it but it might pass it on to your babies. (EV, aged 11).

Only one 14 year-old discussed the inheritance of illness and did so by relating it to her own family experiences:

> it's just that in my family, my granny had whooping cough and scarlet fever and then she had three children and only one of them was quite ill...she had pneumonia. Then, when my dad had me, I had cancer so I don't know if that's actually genetic, if it came in or not. (SB, aged 14; Table 5).

Few children were able to indicate *where in the body genes are found* (Table 6). Statistically significant cross-sectional response trends were found for 10 and 14 year-olds (10 years: χ^2 (3)=14.11, p<.01; 14 years: χ^2 (4)=46.61, p<.001). Many 10 and 14 year-olds said that genes were found in specific organs (24.3% of 10 year-olds and 16.7% of 14 year-olds) such as the brain, stomach or in the blood. The longitudinal analysis showed no statistically significant changes in knowledge of where in the body genes are located. Few adolescents at either time phase said genes were found in cells.

Table 7 shows that most 10 and 14 year-olds stated that you get your genes from your immediate parents (10 years: χ^2 (3)=16.42, p<.001; 14 years: χ^2 (3)=44.78, p<.001).

Table 6 Percentage response to *"Where in the body are genes found?"*

Coding categories	Percentage response							
	Young		Middle		Older		Adolescent	
	T1	T2	T1	T2	T1	T2	T1	T2
Don't know/no response	–	–	–	50.0	59.5	68.8	64.3	48.6
Non–specific	–	–	–	25.0	16.2	18.8	16.7	34.3
Specific organs/tissues	–	–	100	25.0	24.3	12.5	16.7	8.6
Cells/chromosomes	–	–	–	–	–	–	2.4	8.6

T1 and T2 denote time phases

Only 18.9% of 10 year-olds and 16.7% of 14 year-olds stated that an individual would also inherit genes from extended family members. This proportion of responses remained relatively stable over the course of the year.

Responses to *"what happens to your genes when you grow up?"* showed statistically significant cross-sectional response trends (10 years: χ^2 (4)=17.11, p<.01; 14 years: χ^2 (4)= 11.39, p<.02). The majority of respondents (see Table 8) stated that genes would change (51.4% of 10 year-olds and 33.3% of 14 year-olds). Responses suggested that children perceived a relationship between outward physical changes in appearance and changes at a genetic level; "genes could change, like at puberty, it just changes your body" (SV, aged 10), "maybe they change because hair can grow in a different colour" (LB, aged 14). Only 13.5% of 10 year-olds said that genes would be inherited. A higher percentage of 14 year-olds said genes would be passed onto offspring. From their responses, it appears that some older children perceive the actual genes to be passed onto offspring as opposed to copies of genes being inherited. For example, "if you had children, you would pass them down to your children" (JC, aged 10). Longitudinal analysis showed no statistically significant changes in responses for any age cohort.

Most 10 year-olds (χ^2 (1)=18.69, p<.001) and 14 year-olds (χ^2 (1)=87.74, p<.001) believe genes are important. There were statistically significant response trends in explanations for why genes are important for 14 year-olds only (χ^2 (5)=20.26, p<.001). A common reason amongst the 14 year-olds (and 10 year-olds) was that genes maintain individual and family differences. For example, one child stated "because if there weren't genes, everybody would be the same" (RS, aged 10). Children's responses also reflected the importance of belonging to a particular kinship group. For example, "well, if you didn't

Table 7 Percentage response to *"Where do you get your genes from?"*

Coding categories	Percentage response							
	Young		Middle		Older		Adolescent	
	T1	T2	T1	T2	T1	T2	T1	T2
Don't know/no response	–	–	100	25.0	18.9	21.9	11.9	22.9
Parents	–	–	–	75.0	62.2	59.4	71.4	65.7
Extended Family	–	–	–	–	18.9	18.8	16.7	11.4

T1 and T2 denote time phases

Table 8 Percentage response to *"What happens to your genes when you grow up?"*

Coding categories	Percentage response							
	Young		Middle		Older		Adolescent	
	T1	T2	T1	T2	T1	T2	T1	T2
Don't know/no response	–	–	–	25.0	27.0	40.6	23.8	14.3
Change	–	–	100	50.0	51.4	43.8	33.3	40.0
Stay the same	–	–	–	25.0	8.1	3.1	11.9	20.0
Pass onto offspring	–	–	–	–	13.5	12.5	31.0	25.7

T1 and T2 denote time phase

have genes...if you didn't look like your mum or dad, some people might come along and think that your not actually theirs" (EO, aged 10), and:

> because if people didn't have genes...like if somebody had black hair and blue eyes and their child had blonde hair and green eyes, you could tell that they'd been adopted...they don't look like them and people see and think, "oh, he's been adopted. (AP, aged 10)

The 14 year-olds often said genes were important because they determine characteristics. For example: "cause they determine who you are; if you didn't have anything you would just be a blank canvas" (JF, aged 14); "cause if you didn't have them you would be colourless" (LC, aged 14) and "cause if you didn't have some you would be missing a part of your body" (SM, aged 14). Few 14 or 10 year-olds said that genes were essential to life; "cause if you didn't have genes you wouldn't be alive" (CB, aged 10). Longitudinal comparisons showed no statistically significant differences between Time 1 and Time 2 for any of the four age groups (Table 9).

Children's responses to the 'genetic code' question showed that most 10 year-olds (χ^2 (3)=30.16, p<.001) and 14 year-olds (χ^2 (2)=17.52, p<.001) reported that they had never heard the term 'genetic code.' Few children were able to explain what the genetic code meant. Some explanations referred to patterns or codes; "it's like a code that keeps getting born" (RB, aged 10). Only four 14 year-olds mentioned DNA; "it's like DNA has to go in a certain way, but it has to be different for everyone" (LA, aged 14). No age group showed statistically significant longitudinal change in responses to this question.

A similar pattern of findings emerged in awareness of the term 'human genome.' The 10 year-olds (χ^2 (2)=29.20, p<.001) and 14 year-olds (χ^2 (3)=81.83, p<.001) showed low

Table 9 Percentage response to *"Why are genes important?"*

Coding categories	Percentage response							
	Young		Middle		Older		Adolescent	
	T1	T2	T1	T2	T1	T2	T1	T2
Don't know/no response	–	–	–	75.0	16.2	21.9	26.2	31.0
Produces a baby	–	–	–	–	16.2	9.4	7.1	–
Maintains family/individual differences	–	–	100	–	37.8	46.9	28.6	28.6
Determines characteristics			–	25.0	18.9	18.8	33.3	28.6
Essential for life	–	–	–	–	10.8	3.1	4.3	–

T1 and T2 denote time phases

Table 10 Percentage information sources used to learn about genetics

Coding categories	Percentage response							
	Young		Middle		Older		Adolescent	
	T1	T2	T1	T2	T1	T2	T1	T2
Can't remember	–	–	–	25.0	32.4	21.9	31.0	17.1
School	–	–	–	75.0	43.2	46.9	52.4	60.0
Parents	–	–	100	–	8.1	21.9	4.8	11.4
TV/books/internet			–	–	16.2	9.4	11.9	11.4

T1 and T2 denote time phases

levels of awareness. There were no statistically significant longitudinal changes in children's responses.

Finally, there were statistically significant response trends in where children had learnt about genes (10 years: χ^2 (4)=11.56, p<.02; 14 years: χ^2 (4)=34.00, p<.001). The most commonly reported sources were schools (see Table 10). However, a sizeable number of pupils said they couldn't remember how they knew about genes (32.4% of 10 year-olds and 31% of 14 year-olds). There were no longitudinal changes with children's responses to this question.

Discussion

In the discussion, we will (a) summarise the cross-sectional changes, taking each age group in turn and (b) consider the lack of longitudinal findings. Based on the results, we can draw some preliminary conclusions about children's and adolescents understanding of basic genetic concepts and issues for future research.

In line with previous developmental research (Berstein and Cowan 1975), the 4 and 7 year-olds showed some understanding of intra-uterine development but showed little awareness of the origins of gender. Not surprisingly, they had very limited knowledge of genetics (Solomon et al. 1996). By the age of 7 years, over half of the children reported that babies grow in a woman's stomach but the majority were still uncertain about the origins of gender of an offspring. Consistent with Venville et al. (2005), only a minority were aware of the term 'genes' and few could give an explanation of gene functions, location, or origins. There was also a common belief in this age group that genes change with time. Our findings are supportive of the suggestion that 7 year-olds are largely devoid of any genuine knowledge of biological genetics. However, there is evidence that they understand some basic aspects of kinship and inheritance, such as family resemblance, without a detailed knowledge of the biological mechanisms that underpin them (Richards 2000; Solomon et al. 1996; Venville et al. 2005).

Our data reveal statistically significant changes in awareness of the biological processes involved in inheritance at 10 years. By this age, children begin to understand that babies grow inside a womb or uterus. Although the majority of children are still unaware of the origins of gender, nearly a quarter of this age group responded in terms of gene/chromosomes. In line with Venville et al. (2005), we found that many 10 year-olds have a limited conceptual understanding of what genes are and what they do. This may be due to the fact that many of the 10 year-olds in this study had not yet been taught about genetics at school. A variety of functions for genes were given including to 'produce a baby' and ‘determine characteristics’ and no 10 year-old reported that genes were found in cells. Indeed, many of the 10 year-olds seemed to reason about genetics in terms of relationships between kin rather than as a bio-chemical agent (Venville et al. 2005). For example, they believed genes are inherited from immediate parents and this is the first point in development where children mention the role of extended family in the origin of genes. Furthermore, they believe genes are important for maintaining family/individual differences and determining characteristics.

By 14 years, although some changes in concepts of genetics were evident, few adolescents had progressed beyond the understandings of 10 year-olds in this study and those in Venville et al. (2005). We found only three main improvements. Firstly, the 14 year-olds were more likely to know that babies grow inside the womb/uterus. Secondly, more than a quarter of 14 year-olds recognised that genes/chromosomes are responsible for determining gender. Thirdly, there was an increase in the number of 14 year-olds who believed that genes pass onto offspring. From the summaries provided, the greatest shifts in understanding genetics occur between 7 and 10 years with relatively few changes evident between 10 and 14 years.

Taking a closer look at the content of older children’s responses reveals a naïve understanding of genetics that is largely devoid of any scientific knowledge. Two main misconceptions were evident. Firstly, in line with previous work (Venville and Treagust 1998), 10 and 14 year-olds in this study demonstrate a ‘passive particle gene’ concept. That is, they think about genes in terms of what happens to them rather than what they do. The 10 and 14 year-olds perceived genes to be passive entities that are ‘parts of the mum and dad’ that get passed to offspring. Where children mention DNA this not at the level of genes as active agents that control or affect characteristics (see also Venville and Treagust 1998). Indeed, their responses indicated confusion in understanding the relationship between genes, chromosomes and DNA (Lewis et al. 2000a, 2000b, 2000c; Lewis and Wood-Robinson 2000). Secondly, 10 and 14 year-olds talk about genes as ‘trait bearing’ particles, consistent with previous work (Lewis and Kattmann 2004). That is, genes are perceived as ‘things’ that determine your characteristics. Furthermore, the majority of discussions were about genes determining physical traits. This was also evident in their judgements about ‘what happens to genes when you grow up.’ Many children perceived a relationship between changes in outward physical appearance and changes at a genetic level. Rarely did children perceive a relationship between genes and personality traits and they were even less likely to mention illness and disabilities (see also Emslie et al. 2003; Parrott et al. 2003; Smith and Williams 2004).

Interestingly, our findings also suggest that children’s discussion about genes seemed to be strongly focused on kinship relationships and the role of inheritance within families rather than on the structural or functional aspects of genes (Venville et al. 2005). When explaining the importance of genes, children were more likely to construct and reinforce the notion of family identity (e.g., belonging to a particular kinship group) than simply referring to the genetic inheritance of traits. Although our work is preliminary, we suggest that children may use two relatively independent frameworks of reasoning when conceptualising inheritance and genetic processes. The most popular framework is a basic biological and social understanding of genetics, based on a familiar collection of kinship experiences. Our findings and those of existing research suggest that children prefer to conceptualise genetics in terms of everyday social practices and relationships (Richards 2000; Venville et al. 2005). The second framework is an abstract bio-chemical understanding that is characterised by a collection of scientific genetic facts that are not rooted in daily experience. This type of understanding may only be acquired after several years of formal genetics instruction in school. The notion that there may be two ways of conceptualising genetics resonates with the idea that students' scientific reasoning about formal genetics is kept in a 'decontextualised domain of thought' (Da Rosa and Solomon 1998). According to Da Rosa and Solomon (1998), the domain of scientific thought is particularly taxing for school students and one that is not easily accessed when explaining their own inheritance experiences. For children in our study, there appears to be a divergence between understanding inheritance, especially as it relates to their own experiences and concepts of scientific genetics.

An important finding was the lack of longitudinal change in knowledge of genetics at any age. In the present study, no child was taught about genetics at school within the one-year period. Nevertheless, we may have expected some longitudinal change to occur, especially amongst the 10 and 14 year-olds, either through a process of priming from the initial phase of interviews or a more gradual acquisition of facts regarding genetics. There are numerous sources of information about inheritance and genetics which children and adolescents are exposed to in their everyday lives that may influence conceptual development in this area. These include television and the media, conversations with family and friends, direct experience of reproduction, pregnancy and birth in family members and pets, and informal education through zoos and museums. Although speculative, the findings may suggest that children prefer to retain their existing understanding of genetics as 'passive' entities and 'trait bearing' particles within families as opposed to a bio-chemical phenomenon. This may act as a powerful barrier to learning. We suggest that for children to acquire a more scientific understanding of a gene (i.e., as a chemical that codes for the production of proteins) an ontological shift in understanding may be required (see also Chi et al. 1994; Gopnik and Meltzoff 1997; Venville et al. 2005).

Unfortunately, at present, there is very little intervention research on how to generate an ontological shift in genetics understanding. Within the developmental psychology literature, collaborative learning (Williams and Tolmie 2000) and the provision of factual information (Springer 1995) have proved to be successful in enhancing children's understanding of biological inheritance. The relative benefit of these instructional approaches for different ages requires further investigation. Nevertheless, we argue that educators should capitalise on the period between 7 and 10 years of age which not only appears to be a sensitive time for changes in understanding genetics, but where children may be particularly receptive to formal genetics instruction.

This study has shown a variety of cross-sectional changes in children and adolescent's knowledge of the biological processes in inheritance but there are a number of limitations that should be acknowledged. Firstly, we employed a structured interview approach based on published questionnaire studies in order to make our findings comparable to other research. This is both the strength and a weakness of the present study. We did not engage the young people in our study in in-depth conversations about inheritance processes and genetics. When they used the term "genes" or "genetics" we did not probe further to unpack their full understanding of these terms. Future research, taking a qualitative approach, would be invaluable for exploring the meaning young people attribute to these key terms. Furthermore, a wide age range of children was included in this study in order to identify cross-sectional age trends in concepts of inheritance and genes. This necessitated developing interview questions that were appropriate for all ages but limited the opportunity to ask questions designed specifically for certain age groups. It would be interesting to examine in depth within-age variations in concepts of inheritance and genetics by conducting larger-scale studies on particular age groups. Finally, it was not within the scope of the present study to include a cohort of young people who had received formal genetics tuition. Research is required to examine the interaction between formal education concerning genetics and informal learning in conceptual development in this area. It will be essential to include those who have received formal genetics education and those who have not in such studies.

In conclusion, we have identified important cross-sectional findings and a lack of longitudinal change in children's understanding of genetics. The major trends occurred in the late primary years with fewer changes evident between 10 and 14 years. We propose that children have a predominantly biological/social understanding of genetics embedded within notions of family relations and inheritance of traits. A challenge for future research is to identify how ontological shifts required for children to understand formal genetics can be effectively generated in the school classroom.

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Appendix

Q1 Where in the body do babies grow?
1=DK/other, 2=stomach, 3=womb/uterus
Q2 Why are some babies born boys and others are born girls?
1=DK/No response, 2=External, 3=Birth/God, 4=Reference to parents, 5=Boy/Girl sperm, 6=Genes/chromosomes
Q3 Have you ever heard of genes?
1=DK, 2=no, 3=yes
Q4 What are genes?
1=DK/No response, 2=Parts inside body, 3=Part of mum and dad, 4=Traits 5=DNA
Q5 What do genes do?
1=DK/No response, 2=Produce a baby, 3=Similarity to parents, 4=Individual differences, 5=Determine characteristics
Q6 Where in your body are genes found?
1=DK/No response, 2=Non-specific, 3=Specific organs/tissues, 4=Cells/chromosomes
Q7 Where do you get your genes from?
1=DK/No response, 2=Parents, 3=Extended family
Q8 What do you think happens to your genes when you grow up?
1=DK/No response, 2=Change, 3=Stay the same, 4=Pass onto offspring
Q9 Are genes important?
1=DK 2=no, 3=yes
Q10 Why?
1=DK/No response, 2=Produce a baby, 3=Maintains family/individual differences, 4=Determines characteristics, 5=Essential for life
Q11 Have you ever heard of the 'genetic code'?
1=DK, 2=no, 3=yes
Q12 What is meant by the 'genetic code'?
1=DK/No response, 2=Pattern/order, 3=DNA/chromosome
Q13 Have you ever heard of the 'human genome'?
1=DK, 2=no, 3=yes
Q14 What is meant by the 'human genome'?
1=DK/No response, 2=location of genes
Q15 Where have you learnt about genetics?
1=DK/No response, 2=School, 3=Parents, 4=Other (TV, internet, books)

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