Accepted for publication December 2019 in *Journal of the Learning Sciences*

Learning that physics is "not for me": pedagogic work and the cultivation of habitus among Advanced Level physics students

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Abstract

There is widespread agreement that participation in post-compulsory physics needs to be widened and increased, particularly among women and under-represented communities. This paper contributes to understanding of the processes that produce unequal participation, undertaking a Bourdieusian analysis of longitudinal interview data from 75 interviews conducted with fifteen students, tracked since age 10, who studied Advanced level physics in England. The paper discusses evidence of a physics *habitus* that was strongly aligned with notions of intelligence/ cleverness and masculinity and identifies how young women were particularly disadvantaged by a popular notion of the "effortlessly clever physicist", which encouraged even highly interested and high attaining young women not to continue further with the subject. We identified three main forms of *pedagogic work* performed by school physics (attainment-based practices of debarring and gatekeeping; curriculum practices of deferring 'real' physics and physics 'lies'; and interpersonal reinforcement of doxa), which helped cultivate student habitus over time and produce inequitable patterns of participation – suggesting that school physics contributes to reproducing inequitable (and low overall) patterns of participation. Implications are discussed for science education policy and practice to support more equitable participation.

Introduction

"I think I've like always liked physics, but always thought it was quite hard, so maybe not for me" (Kate, age 17/18, Advanced level physics student)

Kate is an exceptionally high-attaining student who was interviewed between the ages of 10 and 18 as part of a longitudinal ten-year study of young people's science and career aspirations. She identifies as a white British, upper-middle-class young woman and at the time of the above interview, was studying an Advanced level physics course at an independent girls' school. Despite attaining very highly in physics (and her other subjects), having a long-standing interest in physics and coming from a science-y family, we were struck that Kate still felt that physics was "maybe not for me". In this respect, she exemplifies some of the long-standing challenges facing physics, namely how to increase and diversify post-compulsory participation and in particular, how to address the persistent under-representation of young women in the subject.

In this paper, we seek to add to understanding of how many young people – but particularly young women – come to see physics as being "not for me", and why these identifications remain so strongly socially patterned by gender, ethnicity and social class. Specifically, we employ a Bourdieusian conceptual lens (e.g. Bourdieu 1990) and key concepts to identify processes through which school science cultivates a particular physics *habitus*, which contributes to the ongoing reproduction of inequalities in physics participation. We identify three forms of *pedagogic work* that are enacted within school physics, which interact with young people's habitus and capital to shape the extent to which they come to see degree level physics as something that might be (im)possible and/or (un)desirable. Moreover, we argue that these processes are highly effective, in that they produce compliance and *symbolic violence*, such that inequalities are attributed to students' own ‘deficiencies’, rather than wider structural inequalities – and which are key to the (re)production of physics’ elite status.

Inequalities in physics participation

Internationally, there is widespread agreement across research, policy and practice that more needs to be done to widen and increase participation in Science, Technology, Engineering and Mathematics (STEM), with the typical graduate in most Western countries continuing to be male, white and middle-class (Campaign for Science and Engineering, 2014; Raelin et al., 2014; U.S. Department of Education, 2015). These concerns are driven by predictions of a continued shortfall in STEM-qualified workers which poses a threat to both national economic competitiveness and active citizenship in an increasingly advanced technological societies (Barton & Upadhyay, 2010; Ro & Knight, 2016; UNESCO, 2010). The issue is particularly acute in the physical sciences and engineering, where low numbers of women pursue these subjects at secondary school and higher educational and professional levels, despite young men and women recording similar levels of academic achievement in science (Institute of Physics, 2012, 2017; Mujtaba & Reiss, 2013).

Within physics, considerable effort has been made to both try to understand the issues facing the discipline and to find ways to attract more students – and especially young women – into post-16 physics (Smail, Whyte, & Kelly, 1982; WISE Campaign, 2017). In the physical sciences, this international underrepresentation of women, and most minority ethnic groups, persists despite a thirty-year history of equality legislation and numerous interventions to recruit and retain a more diverse selection of professionals (Beddoes & Borrego, 2011; Gill, Sharp, Mills, & Franzway, 2008; Sappleton & Takruri-Rizk, 2008).

Various explanations have been put forward to explain the low participation of girls and women in physics, some of the most common being that such differences are due to lower self-confidence and science self-concept among girls (e.g. Green, Martin, & Marsh, 2007) and/or lower levels of physics enjoyment and interest (e.g. Reid, 2003). Consequently, many initiatives have tended to focus either on enthusing (e.g. showing that physics is interesting and fun) and informing (e.g. conveying the uses and benefits of a physics qualification, where physics can lead) or providing individualized inspiration and support for young women, such as through physics role models (Häussler & Hoffmann, 2002; Reid, 2003). However, such approaches have been criticized as offering deficit interpretations, in that young women are seen as 'lacking' (the appropriate confidence, knowledge, interest, etc.). Moreover, despite decades of intervention and funded initiatives based on such premises, there has been little change in post-16 physics participation rates.

Numerous studies have investigated what shapes young women's science participation and how this varies for different young women, such as by social class and 'race'/ethnicity. For instance, Allen and Eisenhart (2017) discuss how four young women of color negotiated STEM identities at school, which involved fighting for particular versions of future self-identity against a discursive backdrop that sought to position them otherwise. Likewise, research has drawn attention to the multiple ways in which school science can deny and offer only limited roles, voice and identity/agency opportunities for low-income, young people of color (Calabrese Barton & Tan, 2010; Carlone, Scott, & Lowder, 2014).

Research suggests that student engagement with a subject is strongly mediated by the extent to which their identity is supported and valued within an educational setting. As Nasir and Hand explain, the closer the perceived link between an individual's identity and a learning context or specific practice, the more likely the person is "to participate more extensively and more intensely" (2008, p. 147). Thus students whose identities do not 'fit' with and are not valued within a particular subject will be less likely to engage with that subject. Indeed, in the case of physics, attention has been drawn to how schools and, in particular, the culture of the science or physics classroom can influence students' identification, or not, with a subject – with the culture of physics being strongly gendered and dominantly aligned with masculinity (e.g. Murphy & Whitelegg, 2006; Danielsson, 2009). As Gonsalves, Danielsson, and Pettersson (2016, p. 1) note, the long-standing association of science with men and masculinity (Keller, 1985), has been "widely documented by feminist science scholars and educational researchers alike" and is particularly heightened within 'hard' science disciplines, such as physics.

Our own prior work has also identified the ways in which physics is dominantly constructed as masculine (Francis et al., 2016) and the discourses which sustain and reproduce this construction. The association of physics with masculinity plays out in various ways across different physics education contexts and settings. For instance, Carlone's (2004) work in the US drew attention to the role of science teachers' gendered expectations of students taking Advanced Placement physics, in which young men were seen as having a "raw talent" for the subject, whereas young women's achievement was stereotyped as achieved through hard work. Much of the research focused on young women's physics participation has been conducted largely within the context of higher education. For instance, Ong's (2005) longitudinal study of ten minority ethnic female physics students drew attention to the gendered, racialized and classed bodily projects that the young women had to engage in, in order to persevere with physics and to 'pass' as legitimate physicists. Traweek's (1988) ethnography of high-energy physicists highlighted the ways in which researchers and university students reproduced the gendered culture of physics, and Hasse's (2002) work highlights how cultural practices operate to align the subject with masculinity. These processes have been noted across international contexts, for instance, Gonsalves et al. (2016) draw on empirical work from Sweden, Canada and the US to identify how particular practices within university physics departments construct and reproduce the association between masculinity and physics. They drew attention to the identity work of women physicists, who reconciled their (positioned) feminine bodies with the dominant masculinity of physics through identity performances of female masculinity and how gender is ascribed to physics experimental equipment and practices and gendered constructions of competence. Pettersson's (2011) ethnography of physics doctoral students underlined not only the frequency, but the everyday nature of these processes, in which talent in physics was dominantly associated with masculinity, and femininity was aligned with incompetence and inauthenticity in physics. These gendered associations threaded through practical work and were even imbued in physics machinery/ equipment (as encapsulated in the application of the term 'boys toys' to high powered physics equipment).

Much of the productive and useful work discussed above has been conducted using theoretical resources from Lave and Wenger's (1991) work on communities of practice and/or Holland, Lachiotte, Skinner, and Cain (1998) work on figured words. Such work has been extremely valuable for foregrounding agency and identities-in-the-making, but it has been argued that there is a comparative lack of research that foregrounds social structure (Shanahan, 2009). With this critique in mind, the present paper undertakes a Bourdieusian analysis, which foregrounds the interplay of structure with agency, in an attempt to further enhance understanding of the processes through which inequalities in physics participation are reproduced through gender, social class and ethnicity.

Through using a qualitative approach and drawing from sociological theory, this paper aims to contribute another perspective to understanding this longstanding issue. A Bourdieusian framework is used to explore and identify dispositions within A level physics student habitus, and the pedagogic work that the subfield of A level physics performs on this habitus. These explorations offer a new way of understanding the intractable nature of the problem of physics participation. Specifically, we identify three distinct forms of pedagogic work that are undertaken and then, in line with our commitment to sociological praxis (Archer et al., 2017), use these analyses to propose some implications for change.

A Bourdieusian conceptual lens

Bourdieu's theory of social reproduction provides a potentially useful conceptual toolkit for researchers who are interested in examining relations of privilege and inequality, particularly with respect to education. While Bourdieu's theory has been used extensively within the sociology of education to explain how schools and universities reproduce wider classed relations of privilege/ subordination, it has been less commonly applied within science education research (although c.f. examples using Bourdieusian concepts in the context of initial teacher education and teacher professional development, e.g. Roth et al, 2000, who use the concept of habitus to explain how teachers "come to act appropriately despite doing so contingently and extemporaneously" p.8 and explore how teacher habitus can be transformed through co-teaching and self-work). We begin by first outlining the foundations of Bourdieu's theory of social reproduction – namely that social relations and practice are produced through the interaction of *habitus* and *capital* within *field*. We then detail how this theory might be applied to understanding longstanding unequal patterns of participation in physics education, making particular use of Bourdieu's concepts of *symbolic violence* and *pedagogic work*.

Habitus refers to the layers of socialised, embodied dispositions that a person develops, which gives them a pre-reflexive 'feel for the game', and a sense of what is normal and desirable for 'people like us'. Bourdieu describes the habitus as "the system of structured, structuring dispositions" (1990, p. 52), meaning that the habitus is a product of socialisation and experiences, that is, habitus is structured by the processes and experiences it encounters within different fields (such as the home, schooling). In turn, this provides a structuring framework that guides how that person experiences, interprets and interacts with the social world (across different fields). The habitus thus produces both “a sense of the game […] and an ability to play the game” (Bourdieu & Waquant, 1992, p. 118). Importantly, Bourdieu argues that the habitus is not just a cognitive schema, but is also embodied (*hexis*), in which socialisation, tastes and dispositions are enacted (and can thus be read) through the body. For instance, he draws attention to how social class can be embodied and read through markers such as accent, style, dress, deportment, and so on. Bourdieu proposes habitus as both individual and collective, that is, habitus is not just a matter of individual cognition but is also shaped by family and community, such that it is possible to discern collective forms of habitus, such as family habitus (e.g. Robb, Dunkley, Boynton, & Greenhalgh, 2007; Thomas, 2002; Tomanovic, 2004) and classed habitus, such as working class habitus (e.g. Bourdieu & Passeron, 1979; Reay et al., 2009). Or as Bourdieu puts it, “the subject is not the instantaneous ego of a sort of singular cogito, but the individual trace of an entire collective history” (Bourdieu, 1990, p. 91).

Capital refers to the range of cultural, social, economic and symbolic resources (or “accumulated labour”, as Bourdieu terms it, 1986, p. 241) that may be possessed and accrued. In this respect, capital is the ‘hand’ you can play in the game. The more a person has of the valued capital in a particular field, or game, the more likely they are to succeed in the game. For instance, by dint of their possession of economic and cultural capital, middle-class families are able to gain advantage through the school system, such as being able to access the ‘best’ schools (Vincent & Ball, 2005). Importantly, Bourdieu asserts that the value of capital is not fixed, but is determined by the field. Indeed, Bourdieu argues that “capital does not exist and function except in relation to a field” (Bourdieu & Wacquant, 1992, p. 101). Hence, dominant groups are able to use education to reproduce their positions of advantage because their capital has a high currency within the field of education. Within any given field, the most powerful forms of capital will be those whose value can be most readily converted into symbolic forms that match the requirements of the field. But the translation and conversion of capital requires considerable labour and effort – it is not an automatic process. Hence dominant groups still need to strategize and work hard to ensure the translation of their capital into social advantage within a field. Capital does not, therefore, exist in isolation or in a singular objectified form – it does not have a set value. Rather, it sits in relation with habitus and field. For instance, particular forms of capital may be embodied in the habitus, notably types of cultural capital (e.g. dispositions, knowledge and understanding of the educational system) and social capital (e.g. relationships). Moreover, while field determines value of capital, the accumulation of capital also, in turn, can shape the field.

Field is more than just a social context – it refers to a socially and historically constructed socio-spatial arena, constituted through the relational positionings of actors. It is a "space of positions and position-taking" (Bourdieu, 1993, p. 30), which Bourdieu imagines as a "force field" that constitutes the *rules of the game*:

> A field is a structured social space, a field of forces, a force field. It contains people who dominate and others who are dominated (Bourdieu, 2010, p. 37)

As Bourdieu and Wacquant discuss, the extent of 'fit' (or not) between habitus, capital and field will shape whether students experience education as a "fish in water", or not (1992, p. 127). Bourdieu conceptualizes fields as overlapping and relational – with subfields within fields, each with its own rules, norms and logic of practice. Hence we propose that there are numerous, overlapping and nested, physics fields, that range from the subfield of a particular teacher's physics classroom, to the wider fields of, say, Advanced level physics, school physics, degree-level physics and of course the field of physics as a discipline, writ large. We suggest that an A level physics classroom can be read as a field, containing differently positioned social actors (e.g. teachers, students) who struggle over a range of (cultural, social and symbolic) capital. Students thus move and operate within and across different physics fields and subfields.

Applying Bourdieu's concepts to physics education

Bourdieu did not apply his theory to specific subject areas and paid scant attention to the field of science. Indeed if anything, his work focused more on the arts, for instance, his theory of cultural capital is almost exclusively formulated in relation to *les beaux arts*. However, his ideas have since been usefully applied to understanding inequalities in science engagement (e.g. Jobér, 2017) and in our previous work we found a Bourdieusian framework helpful for understanding how a young person's sense of whether science is "for me", or not, is shaped by a range of factors, including family habitus (Archer et al., 2012), how much science-related capital (or science capital, Archer et al., 2015) they possess (with science capital understood as being a science-specific subset of wider forms of cultural and social capital) and the extent to which this can be leveraged, or not, across different fields (both in and out of school) (DeWitt and Archer, 2017). We now extend this application of Bourdieusian theory further in an attempt to offer new insights with regard to school physics.

Bourdieu and Wacquant (1992) considered the education system and schools to be key socialising agents, playing an important role in shaping student habitus and reproducing social relations of privilege and inequality. Notably, for Bourdieu, the education system undertakes *pedagogic work*, socialising young people to 'know their place' in the social order and reproducing dominant group values and culture by inculcating students to accept these values (and the unequal social order) as legitimate (Bourdieu & Passeron, 1977). This pedagogic work is achieved through the explicit and implicit practices of schooling, as performed by and through teachers, curricula, education policy, other students, and so on. The purpose of this training is the socialization of students to know their place and to accept dominant social relations of privilege and inequality (e.g. as just the way things are). Bourdieu terms the goal of this inculcation as being *pedagogic action,* that is "the imposition of a cultural arbitrary by an arbitrary power" (Bourdieu and Passeron, 1977/2000, p.5). Hence pedagogic action refers to the achievement of the reproduction of "the cultural arbitrary of the dominant" (Bourdieu & Passeron, 1977/2000, p. 9). Pedagogic work refers to mechanisms and practices through which the goal of pedagogic action might be achieved. For instance, pedagogic work may entail socializing the habitus to accept the dominant system and power relations as legitimate and authentic – in this way, pedagogic work is designed to result in the embodiment of pedagogic action within the habitus. As Bourdieu and Passeron explain, pedagogic work aims to produce sustained, long-term changes within the habitus, namely the development of shared, common long-lasting dispositions that will endure beyond a student's time at school:

> pedagogic work (whether performed by the School, a Church or a Party) has the effect of producing individuals durably and systematically modified by a prolonged and systematic transformative action tending to endow them with the same durable, transposable training (habitus) (Bourdieu & Passeron 1977/2000, p. 196)

The aim of the pedagogic work is thus keeping order by "reproducing the structure of the power relations between the groups or classes" (Bourdieu & Passeron, 1977/2000, pp. 40-41). This is achieved by socialising "members of the dominated groups or classes' to accept 'the legitimacy of the dominant culture" by internalizing values and practices "which best serve the material and symbolic interests of the dominant groups" (ibid.). A key way that pedagogic work is achieved is through *symbolic violence*, which refers to a "process whereby individuals, through their experience of the social world and of the various institutions and structures that compose it, come progressively to develop taken-for-granted ways of thinking and behaving that reflect this lived experience" (Connolly and Healy, 2004 p.16). Such processes can be understood as a pervasive and subtle form of “violence which is exercised upon a social agent with his or her complicity” (Bourdieu and Wacquant, 2002, p. 167). That is, symbolic violence refers to how both dominant and dominated groups may accept ideas or relations that are implicated in sustaining unequal power relations, an example of which might be both male and female students agreeing that boys are ‘naturally’ better at physics than girls.

Hence, pedagogic work involves the shaping and training of a young person’s habitus to accept dominant relations and values (e.g. the association of physics with masculinity) as justified, natural and the way things are (*doxa*). Thus, in turn, doxa reflects the attuning of the habitus to the field:

> Doxa is the relationship of immediate adherence that is established in practice between a habitus and the field to which it is attuned, the pre-verbal taking-for-granted of the world that flows from practical sense (Bourdieu, 1990, p. 68)

As Bourdieu explains, this socialisation of the habitus involves training those who will reproduce the field (in our example, future physicists) and expelling, or debarring, those who threaten this process (e.g. those who do not fit the dominant white, middle-class, male image of physics) – or, as Bourdieu puts it, the process works:

> not only by sanctioning and debarring those who would destroy the game, but by so arranging things, in practice, that the operations of selecting and shaping new entrants (rites of passage, examinations, etc.) are such as to obtain from them that undisputed, pre-reflexive naïve, native compliance with the fundamental presuppositions of the field which is the very definition of doxa (Bourdieu, 1990, p. 68)

Applying Bourdieu’s ideas to the context of A level physics, we would extrapolate that students’ feel for the game of school physics is “produced by experience of the game”

(Bourdieu, 1990, p.66) and that this game would be expected to involve pedagogic work (performed by the field of physics) to cultivate a particular sort of habitus among students which will reflect the demands and interests of the dominant culture of physics. In other words, we expect a students' sense of whether physics is for me, or not, will be shaped by their experiences of (school) physics. Hence, we hypothesize that if we were to find a distinctive shared habitus among A level physics students, then this might indicate that the young people have been subject to some common forms of pedagogic work (institutionalized practices and processes) that have socialised their habitus in these particular ways.

Our proposition raises the question as to what evidence we might expect to see within the student data that could indicate instances of pedagogic work? From our reading of Bourdieu's writing on pedagogic work, and as discussed above, we extrapolate that there are four main types of practice that could be interpreted as evidence or indicators of pedagogic work being undertaken within/by school physics:

- Examples of alignment over time, that is, when students' views and dispositions regarding physics appear to shift and converge over time (becoming more similar to one another), indicating a process of socialization.
- Examples of *symbolic violence*, when students blame themselves for not continuing with physics (e.g. do not see themselves as clever enough).
- Examples of articulations of *doxa*, that is, examples of compliance and acceptance of the status quo (e.g. when students describe unequal participation patterns as just the way things are).
- Examples of debarring and expulsion, that is, when educational systems, processes or institutional figures (e.g. teachers) do not allow and prevent a student from continuing with physics.

In this paper we examine students' accounts to try to better understand how and what the field of physics inculcates and demands of A level physics students, asking: what dispositions are cultivated, what role do these play in how students come to see physics as either for me, or not and what sort of work is involved in this process? Specifically, we ask:

1) What evidence is there, or not, of a distinctive physics habitus among advanced level physics students? What does this habitus look like and how/ does it change over time?

2) What practices (pedagogic work) might be cultivating and shaping the habitus within advanced level physics?

Methods

Data are drawn from the ASPIRSE2 project, a 5-year longitudinal study funded by the UK's Economic and Social Research Council. It follows on from the previous ASPIRES study, which explored children's science and career aspirations from age 10-14. The present study extends the tracking of this cohort from 14-19 years old. The wider project employs a mixed methods approach involving a quantitative online survey of the cohort and repeat (longitudinal) interviews with a selected subsample of students and their parents. This paper reports on qualitative data from 15 students, who at age 17/18 were all of the tracked students who were taking Advanced Level physics and one further student, who had tried to (but was denied) access to A level physics.

The 16 students whose data form the core of the paper, were drawn from a wider sample of 61 17/18 year-old students[i], all of whom had been tracked by the project from age 10/11. Table 1 below shows a summary of the background characteristics and future plans for these students.

Table 1. Summary of participant self-identified background characteristics, physics A level students

Pseudonym	**Gender**	**Ethnicity**	**Social class**	**Post-18 destination/aspiration**
Hannah	F	White British	Upper middle-class	Physics degree
Victor2	M	White British	Middle-class	Physics degree
Neb	M	White British	Upper middle-class	STEM related degree, maths
Tom4	M	British South Asian	Upper middle-class	STEM related degree, maths
Gerrard	M	White Eastern European	Working-class	STEM related degree , maths and computer science
Victoria	F	White British	Middle-class	STEM-related degree, Engineering
Davina	F	White British	Upper middle-class	STEM related degree, chemistry
Josh	M	White British	Middle-class	STEM related degree, computing
Bob	M	Mixed (White British/South Asian)	Upper middle-class	STEM related degree, computing
Preeti	F	British South Asian	Middle-class	STEM related degree, medicine
Mienie	F	South Asian	Middle-class	STEM related degree, natural sciences
Kate	F	White British	Upper middle-class	STEM related degree, natural sciences
Yogi	M	South Asian	Middle-class	Non-STEM degree, architecture/ design
Robert M	M	White British	Upper middle-class	Non-STEM degree, art foundation
Thalia	Other	White British	Middle-class	Non-STEM degree, Japanese
Danielle	F	White British	Working-class	Non-STEM degree, Sociology

Semi-structured interviews lasting approximately 45 minutes each were conducted with the students at five time points: age 10/11, age 12/13, age 13/14, age 15/16, age 17/18, total 75 interviews). Interviews were conducted by one of six interviewers, including the three paper authors. Of the interviewers, five self-identify as white, middle-class women (three British, one Canadian and one American) and one self-identifies as a British Chinese man. All the interviews took place in a private room, usually at school/college or in a couple of cases with the interviews at age 17/18, an alternative private location chosen by the students (e.g. at home, or via telephone). Interviewers communicated to students that their responses would not be shared with their teachers or parents and that they would remain anonymous in any reporting of the data (pseudonyms were chosen by the students themselves at their interview, aged 10, and are used here when reporting individual quotes). Consent was obtained following the guidelines set out by [institution name] and the British Educational Research Association. Pre-determined interview schedules broadly mirrored the survey, in order to explore students' meanings, understandings, experiences and identities in more depth. All interviews were fully transcribed and thematically organized via NVivo. Transcripts were grouped together into cases (one case being the sum of transcripts relating to a particular student) for analysis. Initial coding and sorting of the data (on key topic areas, themes and by responses to particular questions) was undertaken by all authors to help organise the data for subsequent analysis, discussing the codes generated through ongoing meetings, to arrive at shared understandings of what was being coded and how.

The data were then subject to a more conceptually driven analysis, conducted by the lead author. First the students' interview data were searched using the lens of habitus, that is, looking for instances of where students' accounts appeared to refer to particular physics-related attitudes, dispositions and constructions of the extent to which they aligned themselves with, and felt authentic/legitimate participants in physics, or not (e.g. feelings of being good at physics; plans and reasons given for thinking about continuing, or not, with physics post-18). In line with the literature, data were also coded for references to cleverness in relation to science and/or physics. Data were then explored to assess the extent of commonality, or difference, between students' self-constructions (e.g. which students and how students described their reasons for e.g. planning to continue with physics). This analysis revealed a gender difference, whereby only young women seemed to articulate a notion of the effortlessly clever physicist with respect to discussion of their reasons for not continuing with physics and not feeling good enough at physics.

The data were then explored to assess the prevalence, or not, of the four criteria noted earlier as potential evidence of pedagogic work. For instance, the longitudinal data were mapped to note any alignment over time in students' views of physics and the relationship between science/ physics and cleverness and potential examples of symbolic violence (e.g. self blame) were identified.

Once the criteria had been satisfied for evidence of a distinctive physics habitus, and the nature of this habitus, analysis was then undertaken to try to identify potential practices that might be implicated in the production of this habitus. This analytic stage was highly interpretive and involved a process of moving back and forth between the data and the literature. The resultant practices were organized into three main thematic groupings: 1) data where students talked about being allowed or not allowed to continue with physics on the basis of their attainment 2) descriptions of school physics pedagogy, and 3) accounts of others' (but particularly teachers') constructions of physics as hard or unknowable. These groupings were explored using the Bourdieusian lens, for instance to identify the ways through which particular doxa relating to physics were enacted.

Findings

A distinctive physics habitus?

We have previously reported that analysis of survey data from the wider cohort at age 17/18 revealed that A level physics students expressed a number of distinctive attitudes and views, which might be interpreted as potential aspects of a physics habitus (see Archer et al., in press). These analyses showed that, compared not just with all other students, but also in relation to A level science students who were studying biology and/or chemistry (but not physics), A level physics students were significantly more likely to express stereotypical views of scientists, being statistically more likely to agree that scientists are "odd", "geeky" and "male". In other words, it appeared that physics students were statistically significantly more likely than other students (both students in general and those studying science but not physics) to express stereotypical views of scientists.

The qualitative data similarly suggested that, compared to the wider sample of students, A level physics students tended to express a stronger interest in mathematics. They also tended to express similarly positive views regarding the general value of STEM and regarded physics as a male-dominated discipline[ii] (see Archer et al., 2017) and, in particular, as discussed in more detail next, strongly associated physics with cleverness. In other words, taken together, we interpret the qualitative and quantitative data as painting a picture of a distinctive physics habitus that was characterised by an attitudinal profile which associated the subject with intelligence (e.g. personal mathematical academic confidence and self-concept, views of scientists as geeky and strong associations of physics with cleverness) and masculinity (e.g. regarding scientists as male). However, as we will also discuss, we also noted some gendered differences in habitus, with young men and young women positioning themselves differently in relation to these notions of cleverness and their sense of whether physics is potentially for me, or not.

The 'clever' physics habitus

The interviews allowed a more open-ended exploration of students' views about science and physics than was possible with the survey data. Looking at the young people's constructions of those who do science and physics (both in and beyond school), we found a strong, consistent and, in many cases, growing association over time between doing science and being clever. For two of the students (Bob and Tom4), this was a long-standing association, that was evident from their earliest interviews, when they were in primary school, through to their Year 13 interviews. For instance, Bob consistently agreed in all his interviews that people who are into science at school are also "clever", and Tom4 concurred (e.g. "yes, they tend to be", Tom4, age 10/11).

However, for the other students, this association emerged over time, with young people typically refuting an association between cleverness and science in their early interviews, but then shifting their views over time, often during early to mid- secondary years. For instance, after his early assertions that there is "not really" a link, Gerrard's views seemed to shift from his interview at age 10 to his age 13 interview, when he came to espouse the view that "Well yeah, it's mostly clever people". This association was particularly heightened in the case of physics, as Kate put it, "Yeah I think there's definitely this idea that you can only do Physics if you're like super, super clever" (age 15/16). These shifts culminated in a fairly certain acceptance of the association between science, physics and cleverness by the time the young people reached age 18. This pattern was particularly clearly exemplified by Victor, as illustrated by the following excerpts from each of his longitudinal interviews:

Age 10/11: "You don't have to be clever to do science"

Age 12/13: "I think you have to be a little clever because you have to know about Science in the first place […] you probably have to be quite clever in the subject to want to learn about it"

Age 13/14: "People keen on Science … um they're sort of … they're not average people, they're more … they're more clever, they're cleverer than most people"

Age 15/16: "Er, yeah, you need it [cleverness], yes.".

(Victor)

We suggest that this shift in views over time might be interpreted as indicative of cultivation of the habitus across different physics fields because, from a Bourdieusian perspective, the emergence of a shared view over time among a particular community suggests that some sort of process (or pedagogic work) may be at work to produce this specific form of dispositional alignment. We suggest that Victor's examples can be read as conveying the reach and efficacy of this pedagogic work, in that his habitus is cultivated in a coherent and specific way (towards the acceptance that physics is hard and for the clever) across different teachers, institutional contexts (his primary and secondary schools were not connected in any way to one another), curricula and qualifications. We interpret this as suggesting the power and reach of an over-arching disciplinary field of physics that is able to work across time and space, permeating, structuring and operating through and across diverse institutions, actors and educational structures – and which is particularly effective and active during secondary schooling.

A gendered physics habitus? (i) Young men's constructions of physics identity and post-18 choices

We found a similar pattern across both young men and young women whereby the majority of students who completed A level physics did not continue with the subject at degree level. Indeed, just Victor (out of the eight young men who completed Physics A level) and Hannah (out of the five young women who completed the A level[iii]) applied for physics degrees. However, we identified a difference between the young men and women in terms of how they interpreted and narrated the reason for not continuing to study physics after A level. Whereas the young men tended to express confident physics identities and explained decisions not to continue with the subject further as a matter of "choice", the young women tended to express more precarious physics identities and choices which, as we discuss later, we interpret as due to the pernicious effects of popular representations of the 'effortlessly clever' male physicist.

The male physics students whom we interviewed tended to express confident physics identities, positioning themselves as being "strong" (Robert M), "good" (Josh) or "quite good" (Tom4, Neb) at physics, or finding it "easy" (Bob). We interpreted such statements as potential indicators of a physics habitus that is closely aligned with the field, in that they reproduce and concur with popular notions of physics as being a hard, highly academic subject.

Gerrard, Josh, Neb, Robert M and Tom4 had all expressed long-standing post-18 physics aspirations over the course of the study, but these views changed while they were studying for A levels. They all continued to express a strong love and passion for the subject and appreciated its "relevance" (e.g. "I think Physics is more like applicable to the real world than Maths, because like lots, in Maths … is like really abstract. Whereas in Physics you'll sometimes you'll learn something and you'll think 'oh that's how that works' and things like … it's just sort of it's interesting seeing how like these sort of seemingly weird like equations and things in Physics actually apply to things in the real world", Neb). However, for a mixture of reasons detailed below, they applied for other degrees. Three of the young men justified not pursuing physics with reasons couched within external factors, and thus framed their decision as a matter of personal "choice". For instance, Josh and Robert M explained that they had developed an even greater interest in another subject (computing and art, respectively) and Gerrard asserted that it would be indulgent and "selfish" for him to study for a physics degree because of what he perceived as the limited earning potential of physics research careers ("if I only studied what I want to enjoy … I think that's a bit selfish […] because I want to be successful financially as well, just so that I support my parents and just give back to them"). Neb and Tom4 both framed their decision to apply for a mathematics degree as a strategic decision – they believed they would have a better chance of getting highest grades in maths and that it would be "easier" to gain entry to a maths degree compared to a physics degree (due to perceived more attainable entry requirements) and felt it would still enable them to take optional physics modules in their preferred areas of physics:

> "So I was very close to doing either Physics, or Maths and Physics. But the reason I chose Maths was because entrance-wise like in order to get into the unis I think I have a stronger suit in Maths […] I guess it's primarily … I guess the benefit was that I'm better at maths than physics … I'm still quite good at physics but I have a strong suit in maths. (Tom4)

> "Most Maths courses allow you sort of maybe in the second or third year to sort of start to choose, taking like theoretical Physics modules and things like that …Whereas most Physics modules don't allow you to take Maths modules … so I think it makes more sense to me to approach the Physics from a mathematical side" (Neb).

Although, as will be discussed next, in some ways, like many of the young women students, both Neb and Tom4 self-excluded from the possibility of applying for a physics degree, we read their justifications for this decision as being subtley different – namely that they described themselves as being “stronger” in maths than physics, rather than constructing physics as “too hard” – which we interpret as potentially indicative of gendered differences in how young people were able to relate to the possibility of physics.

A gendered habitus? (ii) Young women’s constructions of physics identity and post-18 choices

Of the five young women in our qualitative sample who completed physics A level, only Hannah went on to study for a degree in physics. Preeti followed her long-held aspiration to go into medicine, Kate and Davina dropped their previous physics degree aspirations over the course of their A level studies and Mienie refined her general science aspirations and applied for natural sciences and chemistry degrees. Both Mienie and Kate expressed similar strategic reasoning to Neb and Tom4, indicating that a natural science degree would enable them to take some physics modules, without the challenge of applying for a physics degree. But whereas the young men who changed their physics aspirations gave a range of extrinsic reasons as identified above, as we discuss next, it was notable that Mienie, Kate and Davina (as young women who had previously aspired to physics) explained their decisions based on the feeling that they were “not good enough” to continue.

While all the students associated science and specifically physics with cleverness, we noted a gender-specific construction within the young women’s talk (which we did not find in the young men’s data), in which physicists were aligned not just with cleverness per se, but specifically with the performance of “effortless” achievement, a construction that we termed the effortlessly clever physicist. That is, typically, the young women suggested that it was not just that physicists are highly intelligent (“clever”) but that, specifically, the true (authentic, legitimate) physicist has a “natural” ability in physics (akin to genius) and does not have to work hard in order to understand and excel in the subject, commonly referred to by the students as "breezing through" the subject. Moreover, they located themselves outside this construction, as students who had to "work quite hard" (Mienie, age 17/18) to understand and do well in physics. For instance, even Hannah, who went on to study for a university degree in physics, compared herself unfavourably (as someone who has to "work to understand things" in physics) to those whom she imaged effortlessly "completely breeze through" physics:

> "Well I'd like to think at least that I am good at physics. But not like breeze through it, [I] have to still like work to understand things. So probably like in the middle of that. There'll be people who like completely breeze through it – I'm not one of them" (Hannah, age 17/18).

Hannah was the only girl in the sample who asserted the view that she might be "good at physics", but as her quote shows, she pulled up short of identifying herself with the notion of the effortlessly clever physicist, by qualifying that she does not "breeze through" physics but has to "still like work to understand things". Some, like Davina, identified A level class mates who they felt embodied this ideal whereas others, like Kate, could not point to any known examples, but assumed that these effortlessly clever people existed..

The construction of the effortlessly clever physicist seemed to serve as a key symbolic reference point for all the young women, in relation to their own self-identification with the subject. That is, they interpreted their own ability and viability as a physicist in relation to this dominant construction of the effortlessly clever physicist, which we interpret as internalised within the habitus. Specifically, all of the female A level physics students interviewed expressed the notion that they did not match up to the ideal physics students because they had to exert effort in order to understand and do well in their course. This was particularly explicit in the interviews with Kate and Davina, in which both young women explained that, despite liking the subject and having previously aspired to study it at university, they now felt that they were not "good enough" to take a physics degree. For instance, Davina acknowledged that she had identified strongly with physics in her previous interviews ("like definitely I was more like a physics… person", age 17/18), yet decided in the end to apply for a chemistry degree, which, despite her high attainment, she related to a sense of not feeling "clever enough" to do physics:

> "I mean certainly if someone said 'do you think you're clever enough to do physics at university?' I would say definitely not, most definitely not … like no way I could do physics at university. … I mean maybe this is because I have quite high standards … for most things in science I do tend to understand them like first time. But like whereas like I feel at A level I don't … So like I think like … I mean I guess I'm probably smart enough to like get the A level, and then I don't think that necessarily means that I'm actually like that *good* at physics, if you know what I mean" (Davina, age 17/18).

As Davina further explained:

> "part of the reason why I probably feel like I'm not good enough to do it [physics] further [is] because I'm comparing myself to other people who are like … like really, really good at these things. […] Part of the reason why I'm maybe putting myself down slightly is probably because I'm comparing myself to people who are just kind of like … you know kind of again pretty much breezing through and getting like you know 80% or whatever. And then I'm there like trying really hard and getting less than that."

One possible explanation for this pattern, as Davina hinted at, is that the young women who felt they did not match up were those who were not attaining well. However, when we examined attainment, this hypothesis was not borne out. For instance, while Davina worried that she was not attaining the very highest grades, she still attained A grades in all her subjects. Moreover, Kate recorded the highest attainment of the whole qualitative sample, but she still worried that "I just don't really understand it [physics] that well" and, despite arguably being one of, if not the, strongest student (attainment-wise) in her physics class, she felt that the effort she exerted to produce this high attainment meant that she fell short of the imagined, idealised (effortlessly clever) physics student and hence came to see the subject as “maybe not for me”:

> “I wouldn’t do like a straight physics degree, because it would be too hard. Like I think I’m just a bit put off by thinking that it would be really hard. […] So yeah, I think what put me off doing straight physics was that I think it’s too hard and what put me off straight Biology is I’d quite like to do some physics as well. (Kate, age 17/18).

Kate’s concern that physics is “quite hard, so maybe not for me”, despite her being the highest attaining student in our sample, potentially reveals something distinctive about the field of physics – namely that it inculcates the expectation that only the cleverest and highest attaining students are legitimate participants, and that even these students struggle to see themselves as potential physicists.

Evidence of pedagogic work?

Applying our four criteria to assess the evidence for whether the above findings might be reasonably interpreted as examples of pedagogic work upon the habitus, we did find instances of alignment over time, symbolic violence and doxa. Firstly, looking at the longitudinal data, we found that the young women’s common perception (of the self as failing to match up to the ideal of the effortlessly clever physicist) seemed to emerge over time. That is, most of the young women taking A level physics had expressed more confident physics identities in earlier interviews and became less confident in their later interviews, but particularly over the course of taking the subject at A level. Mienie summed this up:

> “I mean physics is really hard but I enjoy physics even though it is quite hard. I have to work quite hard for it …yeah, I don’t know why but it’s, I don’t know, because some things come naturally to you and physics, *it did*, but then…” [emphasis added]

As illustrated in the above quote, Mienie underlined her enjoyment of physics and, like her peers, recognised that her understanding and attainment is achieved by having to "work quite hard for it". She juxtaposed this with the notion of effortless achievement ("some things come naturally to you") and noted that she has experienced a change over time – she *used* to find that that physics came "naturally" to her, but this is not the case anymore ("some things come naturally to you and physics, it did, but then…", age 17/18). Similarly, Davina also reflected, somewhat ruefully, that whereas she usually finds that she understands concepts and content quickly and easily in the other sciences ("for most things in science I do tend to understand them like first time", age 17/18), but the case of A level physics, she felt "I don't". We thus interpret this shift over time regarding young women's growing acceptance that the authentic physicist is one whose attainment and ability is "natural" (rather than the result of hard work), as potentially evidence of the impact of cultivation of the habitus via pedagogic work that occurs over the course of A level physics. Moreover, the difference in patterns between young men's and young women's talk could suggest that this is a specifically gendered form of pedagogic work which, from a Bourdieusian perspective, might be interpreted as designed to achieve the pedagogic action of maintaining the elite association of physics with masculinity.

We also noted potential examples of *symbolic violence* in the form of the young women's acceptance of gendered patterns of participation in physics (as 'normal') and their internalisation that their exclusion from the subject is due to their own failings (e.g. lack of ability, aptitude), rather than being the result of, say, the unequal distribution of capital or (as discussed in the next section, where specific forms of pedagogic work are identified), inequalities in how the is subject organized and assessed. For instance, Davina and Kate's transcripts provide particularly clear notions of symbolic violence, as expressed through their constructions of natural or essentialised physics cleverness and their self-blame and self-exclusion on the basis of being "not clever enough" to take the subject further (particularly given their high levels of attainment). We suggest that it is also possible to read some of the male physics students' accounts as potentially hinting at the association of physics with extreme cleverness and a potential gap between this and the self (not least given Neb's comment that he now felt that maths came more "naturally" to him than physics), but on the whole, we interpret the young men's accounts as not exhibiting the same level of self-deprecation as the young women's. As Jenkins explains, from a Bourdieusian perspective, symbolic domination is achieved through the self-regulation of the cultured habitus, "exclusion works most powerfully as self-exclusion" (2006, p.107).

Part 2: Identifying pedagogic work in A level physics

So far we have set out evidence of: (i) a distinctive habitus among A level physics students, which includes a particularly strong association between physics and cleverness, which emerges/ is consolidated over time (which we argued indicates the potential existence of pedagogic work in cultivating this habitus); and (ii) a shared notion of the effortlessly clever physicist among young women, which they felt they did not measure up to and which was implicated in a number of the young women's self-exclusion from degree level physics, even when they loved the subject and attained well in it. We suggested that the consolidation of these views over time, along with instances of self-blame that hint at symbolic violence that we identified in the data, suggest the existence of some sort of pedagogic work that operated to cultivate these dispositions and produce gendered trajectories in physics. Having made this case, we now move on to try to identify specific forms of pedagogic work that might be operating in and through A level physics to produce these patterns. As discussed next, our analysis identified three main forms of pedagogic work:

- Attainment-based institutional practices of debarring and gatekeeping [helps produce clever alignment and making self feel precarious]
- Curriculum practices (physics 'lies' and deferment of 'real' physics) [to reinforce idea of clever and precarity]
- Interpersonal doxic reproduction (the 'boy brain') [to produce natural alignment of physics and masculinity).

Attainment-based institutional practices of debarring and gatekeeping

We examined the data of not just the 13 students who completed A level physics, but also the one student (Danielle) who had applied to take A level physics but who had not commenced the course and the two students (Thalia and Victoria) who had started the course but not completed it. This examination highlighted the operation of stringent practices of institutional gatekeeping, in which access to, and continuation in, physics A level was tightly regulated by the extent to which students could continue to produce sufficiently high academic attainment.

For instance, Danielle loved physics and had wanted to study the subject at A level but was told by her school that her attainment in the national GCSE examinations at age 16 (namely achieving a B grade in science) was not sufficiently high to enable her to enter A level physics (see Archer et al., 2017 for a detailed discussion of Danielle's case). The entry requirement of an A or A* grade sets physics apart from most other A level subjects, which typically operate less stringent entry criteria (see OfQual, 2017; Tracy, 2016). Danielle initially challenged the school's decision and was granted a potential trial period, however, prior to the start of the course, she recounted how teachers went to considerable lengths to explain to her that she would likely "struggle" and should reconsider ("I got put off because apparently it's really hard", age 17/18). Danielle eventually decided not to take up the trial offer and chose Sociology instead. She reflected on her disappointment ("at the time I was upset") but reconciled herself to this being probably the 'right' decision, "cos I know so many people that are like failing science […] like *really* failing" (age 17/18 interview), hinting at potential symbolic violence.

Thalia and Victoria both commenced physics A level but were expelled from the course by their respective institutions at the end of their first year of study. In both cases, this decision was made on the basis that neither had attained highly enough to date in the course. Both students accepted the legitimacy of the decisions and attributed the failure to themselves and their own (alleged) lack of ability, even though they attained well previously:

> "I didn't click with any of the Physics. I feel like that was always a bit hopeless, but I got a B at GCSE, but that compared to A level it's just not even comparable" (Victoria, age 17/18)

Using a Bourdieusian lens, all three students might be read as exemplifying what Bourdieu terms *practical faith* – whereby practices of institutional debarring are designed to obtain "native compliance" (Bourdieu, 1990, p.68). That is, the students do not question their exclusion but rather accept as legitimate the arbitrary (and differential) application of higher attainment requirements in physics. We interpret these attainment practices as examples of what Bourdieu refers to as practices of debarring (Bourdieu, 1990, p.68). As discussed in earlier sections, among those students who completed physics A level, there were also concerns expressed by both young men and young women that entry to a physics degree would be exceptionally difficult, with particularly tight entry criteria that exceeded those perceived to be enacted by other STEM degree areas, such as mathematics.

From a Bourdieusian perspective, we interpret the underlying function of these practices as being to socialise students to accept that physics is different and special in that it is an exceptionally difficult subject that is only for the ‘clever’ few. That is, rather than being objective requirements, we interpret the enactment of strict entry and retention attainment-based criteria in physics as examples of arbitrary institutional practice (pedagogic work) that are designed to support the underlying pedagogic action, which is to maintain the elite (white, male, middle-class) culture and status of physics (through its continued, close association with notions of exceptional cleverness which, as previously argued, is in turn aligned with dominant social groups).

While our data set is too small to discern what significance should be attributed to the fact that these processes of attainment-based institutional debarring in A level physics were only noted in relation to young women (Danielle, Thalia and Victoria), we suggest that this raises an area of concern for further research.

Curriculum practices (deferment of ‘real’ physics and physics ‘lies’)

So far, our analyses have prompted us to consider whether there might be some common practices within the students’ experiences of A level physics that were contributing to shaping both a common habitus but which also played out differentially across gender. Given that the young people we interviewed attended a range of schools and colleges across the country, we wondered if there might be something about the shared curriculum that was contributing to these patterns. We thus interrogated the data with respect to how students described the content of their courses.

Students commonly felt that A level physics conveyed a distinction between real physics and school physics, namely that they felt that real physics remained at a distance (with school physics being a simplified proxy), which they were not allowed access to due to their supposed intellectual immaturity. As Davina explained at age 17/18, although she felt reasonably confident that she is “smart enough to like get the A level” (which she later explained would mean, for her, attaining “a solid A” grade), she did not believe that this meant that attaining a top grade at A level meant that she is “actually like that good at physics”. In other words, like other students, she felt that there was a disconnect between school (A level) physics and real physics, a disconnect that has been noted in previous research (e.g. Hodson 2014). As we discuss next, real physics was configured as physics at degree level (and beyond) and school physics was configured as an arbitrarily (over)simplified version of physics, with some simplifications being stretched to the point of being “untrue”. Two main practices were identified: physics lies (i.e. over-simplifications of physics facts that are later revealed to be “false”) and the systematic deferment of the real (interesting) physics within school physics. We address each in turn.

School physics ‘lies’. When talking about their views and experience of physics, several of the students recounted their surprise and frustration on realising that some of the physics facts that they had learned at earlier stages of their schooling, were later revealed to be over-simplifications. Josh, Tom4 and Thalia all provided eloquent illustrations of this (with emphasis added):

“Because it’s so complex, you learn simple things in secondary school that you actually find out **aren’t true** when you get to [A level]. Um, an example would be gravitational potential energy [*explains example and equation*]. And you use that at secondary school, but like I said earlier you actually find out that **that’s not true**. [*Int: Okay.* [*Laughs*] So at school you just picture it as that’s true as high as you go, if you know what I mean. Um, but you actually find that it isn’t. […] And then the actual equation … is completely different. […] I feel like at secondary school they should, they have to teach you the simpler parts of it, but they should still tell you that that's not the true case, because you get in your head that that's all right, um, I don't know… I suppose you just grow up and then you actually learn it properly [laughs]" (Josh, emphasis added)

> "I think the best way I've had it put is they're just … they're just **lies that slowly slowly become less lies**. So as you go up … [*Int: laughs*] So you are told that 'oh an atom is just a circle with this in it'. At Key Stage 3 let's say you're told right at the end … and then at GCSE you're told 'oh it's actually lots of circles and a ring around it'. And then at A level you're told 'oh no that's wrong, it's this with this structure'. And then second year, you're told 'this is the structure, but this is overcomplicated'" (Tom4, emphasis added)

> "… Like, I understand what they do lower down the school is like they have to simplify it for students, but honestly as I get older and then they're like 'oh in Year 7 [age 11/12] we taught you this, **but really that's not how it works'**. Like I find that very hard to get a foundation down from physics, … I think you need the balance of like simplicity and getting a real strong framework down […] Yeah, it's usually just like really simple stuff, like little things, but for me I find it very confusing, because I'm like 'but I've thought this for my entire school career and now I have to think a different way' …. It's just little things like that help put me off […] even at A level like I'm very well aware that there's things that they don't tell us about, because it's, we don't have the knowledge for it […] That really makes me dread physics, because I'm like 'if I'm not going to learn it at A level, when am I going to learn it?**"** (Thalia, age 17/18)

These three students all attended different schools and were studying different A level syllabi. However, they expressed remarkably similar views on the 'mendacity' of physics through its over-simplification. We cannot be certain from our data, but it seems possible that the practices that the students referred to as physics ‘lies’ may derive from their experiences of spiral curriculum approaches (Bruner, 1960), which are common in science education and physics education in the UK and other countries and in which students are introduced and re-exposed over time to the same concept through increasing levels of complexity. In this respect, the students’ negative interpretations of such approaches provides food for thought for educators, given that spiral curriculum approaches are generally viewed as providing helpful learning tools. It is also possible to interpret the students’ accounts as highlighting an ongoing struggle to move away from fact-based pedagogy in this field (see Osborne et al., 2014), the ‘stickiness’ of which, from a Bourdieusian perspective, is because traditional, didactic pedagogies are often popularly interpreted as signalling eliteness and the difficulty of a subject.

Applying a Bourdieusian lens, we suggest that such accounts can be interpreted as hinting at the traces of pedagogic action upon the habitus – that is, pedagogic work that is routinely undertaken through curricula and teaching which inculcates within students the notion that real physics is, highly conceptually difficult and, to an extent, unknowable by school students. Moreover, students seemed to suggest that they felt this ontological dilemma was particular to physics, and was not common across other school subjects, in which they might either access the “real” content directly (for instance, reading original texts in English), or which they described as being more “opinion-based” than “factual”, or tended to have a clearer and more open relationship with higher level concepts and content. For instance, Thalia explained that other teachers, such as their psychology A level teacher, would signpost and mention topics and concepts that would be addressed at degree level, “whereas I feel like in physics you wouldn’t want to ask” (age 17/18).

Deferment of the "interesting bits" (test of endurance). In addition to the deferment of real physics through its simplification into (not real) school physics, students also complained about the deferment of gratification enforced by the common curricula practice of not covering the "interesting bits" of physics until A level and beyond. For instance, Neb and Gerrard both complained about the lack of the "really interesting" physics on the A level syllabus. Indeed, all the physics students complained that much of the physics they had learned over their school career had been "dull" and not the "really interesting stuff":

> "The topics I'm mainly interested in are the more theoretical, the more mathematical side of physics, which you don't really do at physics A level [...] I think as well with the syllabus, um, often it covers what the examiners deem important and less what students find interesting [...] All these concepts that they talk about on like TV programmes like black holes and things like that, those are never covered and those I think are what people find interesting, [...] but I think if they could be like talked about conceptually at earlier levels then people would be much more interested." (Neb)
>
> "[Last year] the content of physics was so dull, ... we did 13 chapters last year, I looked forward to *one* out of those 13, and that was quantum. ... The thing that kind of kept me going was that this year's physics may be dull, but you need to learn the basics to do the second year. And the second year – that was so fantastic, cos you're doing gravity using cosmology, you're doing nuclear physics, you're looking at quarks and stuff that make up everything in this universe ... I think Year 13 [age 17/18] physics is fantastic. Year 12 is drab, ... something I told quite a few people when they were picking physics is be prepared that Year 12 is extremely dull..." (Tom4)
>
> "We did like some quantum physics last year which I liked, but the rest of it was pretty like bog standard" (Hannah)

> "Um, well 100% in physics I was waiting for it to get more interesting during like GCSE and then the first year of A level as well we did like Mechanics stuff that isn't very interesting, but like just this morning actually we just started particle physics and so that's more interesting. It's taken a while for us to get there, but it is more interesting" (Kate)

While of course we might expect students in any subject area to express the view that some topic areas are dull while others are interesting, we did note a greater consensus among physics students compared to other A level subject areas. That is, physics students were generally more likely to identify a sharp divide between "boring" and interesting topics in their curricula and they expressed more consistent views among themselves as to which of these areas were interesting (e.g. quantum theory) or boring (e.g. mechanics).

We suggest that the deferment of interesting (namely quantum) physics and the requirement for students to first learn a particular canon of boring fundamental work before they are allowed to progress to the interesting topics, can be interpreted as a form of pedagogic work that is conducted through the construction of the physics curriculum and syllabus to reinforce the binary distinction between real versus school physics. The arbitrary nature of the school physics curricula was, indeed, explicitly identified by Neb, who asserted that the curriculum is not designed to engage students, or to include "what people find interesting", but rather has the purpose of canonising the cultural arbitrary of the powerful, or as he put it, "what the examiners deem important" (age 17/18).

In this vein, we suggest that school physics emerges as a paradoxical illusion of physics – it is, and yet it is not, physics, because the real physics is split off and deferred. We interpret these processes of distinction as forms of pedagogic work designed to reproduce the elitism of physics, in which real physics is reserved only for the privileged few who have the requisite habitus, capital and endurance to finally attain it.

Interpersonal reinforcement of doxa

The students all identified examples of when others (but particularly institutional actors, such as teachers) had reinforced aspects of the doxa of physics (as exceptionally difficult, associated with masculinity, as distant from school physics) through their everyday talk and interactions. For instance, as illustrated by Thalia, the students recounted examples of how their teachers had underlined the difficulty of physics. Thalia described how a physics teacher had explicitly told the class that the subject was not just hard, but too hard to be understood fully by students:

> "So I don't know whether it's just that or whether it is just because there is the stigma of it is really hard, and like I've been told in lessons by [teachers] 'if you think you understood this concept you didn't understand it at all' and I'm like 'oh great!' […] Um, but like I think a lot of that kind of doesn't help. Because like if no one's going to understand it, how are we going to be good at it?" (Thalia, age 17/18)

We interpret Thalia's lament ("if no one's going to understand it, how are we going to be good at it?") as hinting at the pedagogic action underlying such practices – namely, as typical of the myriad of small acts that are undertaken which aid the reproduction of the elite status of physics by restricting entry for all but a privileged few. That is, we suggest that the students' accounts hinted at pedagogic work which is undertaken within the teaching and learning of A level physics which inculcates students to accept that physics is too hard for all but the natural, effortlessly clever, genius physicist – and that the propagation of this fantasy is an integral part of the reproduction of the elite status of the subject.

As has been noted in the wider literature (e.g. Francis et al., 2016), young women in our sample recounted various instances when significant others (such as teachers, parents, peers) had expressed gender stereotypical views that aligned physics (and related areas, such as engineering) with masculinity. For instance, one young woman, Poppy, (from the wider student sample) explained that her chemistry teacher had told her that you “need a boy brain” to study advanced level mathematics and recounted an exchange with her physics teacher at a parent consultation evening during a discussion as to whether she might take advanced level physics:

> “She [physics teacher] said ‘you can usually tell the girls who want to do physics, they look a bit tomboyish’ and then she could see my parents’ faces and me … and she’s like ‘oh no, you’re not tomboyish’ and then she tried to change it… And this physics teacher, I don’t know, I think, I just –it shouldn’t be like that at all” (Poppy, age 15/16).

Perhaps unsurprisingly, Poppy did not opt for advanced level physics, but pursued the other sciences and mathematics at A level and applied for a natural sciences degree.

As Gonsalves writes, “the scientific mind is … regarded to be, simultaneously and contradictorily, disembodied and male” (2014, p. 505). We further suggest that this dominant notion of the masculine scientific and mathematical mind may be further amplified in the case of physics, as it mutually reinforces with the gendered stereotype of the effortlessly clever physicist.

Discussion

In this paper we have sought to contribute to existing work on students’ (non)participation in post-compulsory physics, through a Bourdieusian analysis of longitudinal qualitative data that were collected as part of a longitudinal study, tracking students’ science and career choices from age 10-18. We identified some shared clusters of attitudes and dispositions among advanced level physics students, which we interpreted as signalling a potential physics habitus. One of the core elements of this habitus was an association of science, but particularly physics, with cleverness. The construction of physics as a difficult or hard subject is longstanding (e.g. Duckworth & Entwistle, 1974) and difficulty is a primary reason given by students for decisions not to pursue the subject post-16 (e.g. Tripney et al., 2010). However in this paper, we attempted to unpack some of the ways in which this association is re/produced and becomes embodied in the habitus of physics students, which in turn helps to sustain the reproduction of physics as a hard, masculine and elite subject. That is, we tried to trace how and why it is not just that the only students who continue with physics are those who attain highly in the subject, but how gendered notions of cleverness and physics produce patterns in who 'chooses' to continue with physics, such that even high attaining students, such as Kate, whose reflections opened the paper, come to see the subject as not for me. We also identified some particular gendered dimensions of this habitus, focusing in particular on a construction of the effortlessly clever physicist which was predominantly voiced by young women and which seemed to be implicated in some young women's self-exclusion from degree level physics, even where these young women recorded high interest and attainment in the subject.

Applying our conceptual lens, we identified evidence of alignment in student attitudes over time, which we interpreted as produced by pedagogic work on the habitus to produce these dispositions. Having satisfied our basic criteria for evidence of pedagogic work processes in the data, we then went on to identify three main forms of pedagogic work that was performed by school physics (contributing to the emergence of these patterns in student habitus), namely attainment-based practices (which include practices of debarring and exclusion, thus also satisfying our fourth criteria for evidence of pedagogic work), curriculum practices and interpersonal doxic reproduction.

We suggest that our findings help build on and extend existing research on the everyday gendered practices within university physics which normalise masculinity and exclude femininity (e.g. Danielsson, 2009; Gonsalves et al., 2016; Petersson, 2011) and research on school students' identifications with science (e.g. Francis et al., 2016) by illuminating some of the subtle, yet pervasive and everyday ways in which school physics cultivates a distinctive habitus among physics students and 'weeds out' those who do not 'fit' or conform and ensures that those who do continue with the subject are socialised to accept (and in turn help embody) the doxa of physics as hard and masculine. We argue that these practices can be understood as driven by (and thus helping to reproduce) the elite status of physics, exemplifing what Bourdieu terms:

> the long dialectical process, often described as 'vocation', through which the various fields provide themselves with agents equipped with the habitus needed to make them work (Bourdieu, 1990, p. 67)

That is, the examples of pedagogic work we identified are designed to achieve the purpose of reproducing and maintaining the elite status of physics. We propose that this daily pedagogic work (as enacted through everyday attainment-based, curricula and interpersonal educational practices), plays an important part in producing predictable patterns in habitus across students, shaping the likelihood of a student coming to see post-18 physics as for me, or not, in predictably gendered ways.

One of the limitations of the analyses reported here is that we have not had the space or data from which to unpack interactions of gender with social class and ethnicity – either in relation to the students who took A level physics (who were predominantly from middle-class, White or South Asian families) or in relation to the inequalities that operated to weed out and exclude working-class and Black students prior to entry to A level physics. However, drawing on the wider literature, we understand notions of 'cleverness' – and in particular the ideal of effortless achievement – as inherently classed, gendered and racialized constructions. Here we are informed by an extensive feminist explication of how academic attainment is dominantly constructed along gendered lines, such that examples of young men's attainment tend to be attributed to natural ability, whereas young women's achievement is often explained away as due to hard work and plodding diligence (e.g. see Francis, 2005). This gendered association has also been noted specifically in relation to post-16 physics, as Carlone's (2004) study of students taking advanced placement physics poignantly details. Bourdieu (1996/2010) also writes how notions of differential intelligence and cleverness are integral to the production of classed inequalities, such that intelligence is aligned with middle-classness, whereas the working-classes are assumed to be 'ignorant', 'unintelligent' and hence deserving/ requiring of domination. Moreover, there is also a long post-colonial critique of how white societies have oppressed and justified their domination of people of color through racialized constructions of intelligence – which, as critics identify, have also been propagated through psychological research and the notion of intelligence as genetic (Archer and Francis, 2007).

These strands have been brought together in some of our previous work, in which we set out a conceptual framework to explicate how, within dominant discourse, gendered, racialized and classed inequalities combine to differentially, but consistently, produce the identity of the 'ideal student' as aligned with white, middle-class, masculinity – thus excluding and pathologising Other students (see Archer, 2008; Archer and Francis, 2007). Extending this model to the context of A level physics students, we suggest here that the associations of physics with cleverness, and specifically effortless cleverness, can be understood as key technologies in the reproduction of the elite status of physics, which enables the subject to retain its elite status through its alignment with white, middle-class masculinity. This assertion – that physics is dominantly aligned with white, middle-class masculinity – is of course, not new (e.g., Ong, 2005, Gonsalves 2014, Danielsson, 2009), however what we seek to add to this picture is that this is not just a static historical association but is one that is actively reproduced through the hidden pedagogic work that is performed by school physics, which helps cultivate particular dispositions among students, such that they come not just to accept the status quo as legitimate and the way things are (doxa) and persuades those who do not embody and 'fit' the dominant culture of physics to self-exclude. Moreover, we suggest that this cultivated habitus will likely help ensure that the next generation of physicists will also continue to reproduce the field in these ways.

But why does school physics do this? From a Bourdieusian perspective, the purpose of pedagogic work is the reproduction of dominant relations of privilege and inequality. As a high status subject, aligned with masculinity and with post-16 physics qualifications commanding a strong exchange value in the labour market, we understand pedagogic work as being enacted within school physics in order to maintain the order and dominant status of the subject. Indeed, as Bourdieu (1984) argues, historically the stability and eliteness of high status professions (but particularly those based on high levels of educational capital) has depended on their "deliberate" gate-keeping policies which "prevented numerical growth and feminization and helped to maintain scarcity value" (p.137). In other words, we suggest that the practices we have identified are not random or happenstance – they play a key role in the reproduction of physics as an elite subject by restricting both the number and diversity of those entering the profession. Through such practices, physics is able to maintain its high status in relation to other subjects generally and other science subjects specifically. Moreover, these practices also ensure that those students who do continue into post-18 physics are equipped with a habitus that will support and enable the ongoing elite reproduction of the field. Indeed, it might be argued that the production of a habitus that relates to physics by questioning "am I good enough?" is both effective for propagating the elitism and dominance of physics and to producing the high attainment that is both required for, and in turn reinforcing of, the high status of the subject. Hence, these practices help perpetuate and legitimate patterns of unequal participation in physics, to the benefit of students from socially dominant backgrounds. In this way, the predominance of white, middle-class men in post-compulsory physics is understood as deserved and achieved by dint of their (allegedly) superior natural abilities (Bourdieu & Passeron, 1977), rather than being produced through practices such as pedagogic work. Our data suggest that the pedagogic work enacted through school physics is arguably highly successful in this respect, as participation patterns in post-compulsory physics have remained narrow and highly resistant to change over time, despite considerable attempts at intervention.

We suggest that the over-representation of socially advantaged students (e.g. boys, middle-class and white students) in post-compulsory physics can be understood as potentially exemplifying symbolic violence, in that non-dominant students have been socialised to accept their exclusion from physics by dint of not feeling clever enough. Indeed, most of the students we interviewed seemed not to question the high entry bar, highly selective nature of the subject nor their own self-exclusion and/or debarring and feelings of inadequacy, even when highly qualified, as exemplified so clearly in the case of Kate. As Bourdieu and Passeron explain:

> "The specific productivity of pedagogic work is objectively measured by the degree to which it produces its essential effect of inculcation, i.e. it effect of reproduction" (Bourdieu and Passeron, 1977/2000, p. 33)

Bourdieu argues that the productivity of pedagogic work depends on the extent to which it can produce durable and transposable dispositions in the habitus, that is, dispositions which last over time and which can be applied to different contexts. While our longitudinal tracking of the students currently records only eight years of their early lives, we suggest that the level of consensus among these students regarding the nature of physics, and realisation among so many of them – but particularly among the girls – that post-18 physics is not for me, irrespective of personal interest and attainment, might be taken as indicators of the productivity of pedagogic work . In this respect, we hypothesise that the existing profile of participation in post-compulsory physics is set to continue – whereby most students will continue to be socialised to accept both the elitism of physics and, their own unworthiness to study it further, without the need for overtly repressive practices.

Implications for physics participation

Based on our findings, we suggest that there is currently little reason to assume that common existing interventions which are based on individualised approaches to enthusing, inspiring and informing students about physics (such as those offered by professional physics societies, charities and industry) are likely to lead to any significant changes in the numbers or profile of those participating in post-compulsory physics. This is because our findings suggest that it is primarily gate-keeping practices within and by school physics that play a key part in producing low and unrepresentative patterns of participation in physics. This is not to say that we see no wider benefits to be derived from wider inspiration-based physics interventions, but rather, our findings suggest that such approaches do not fundamentally address some of the important school-based processes and practices which play a key role in producing uneven and low patterns in physics participation, and so are unlikely to have a significant impact on participation.

Moreover, we interpret our data as suggesting that there is little evidence that the culture of physics will change in the foreseeable future, or that the new/ next generation of physicists will hold more inclusive or egalitarian views of the subject (thus facilitating changes in participation rates). Rather, we suggest that our findings regarding the gender stereotypical dispositions of advanced level physics students (e.g. being statistically more likely to see scientists as odd, geeky and male; constructions of the effortlessly clever physicist), indicate that the next generation has already been effectively socialised to reproduce the dominant culture and associations of physics. As Bourdieu explains:

> The earlier a player enters the game and the less he [sic] is aware of the associated learning… the greater is his ignorance of all that is tacitly granted through his investment in the field [...] thereby reproducing the conditions of its own perpetuation (Bourdieu, 1990, p. 67).

Bourdieu argues that "native membership" of a field produces a feel for the game and means that the rules and values of the field are taken for granted and that "everything that takes place in it seems sensible: full of sense and objectively directed in a judicious direction" (Bourdieu, 1990, p.66). In this respect, we suggest that one way forward could be the engagement of researchers, professionals and activists from *beyond* the field of physics and science (such as from the social sciences and those who engage in social justice work with teachers and young people more broadly), to help support those within the field of physics (e.g. through initial teacher education and continuing professional development) and those within school science education policy communities to engage in critical reflection and look afresh at the institutional and interpersonal processes and practices which combine to produce patterns of inequality within the subject.

While recognising the necessarily limited potential for generalising from such a small and specific sample, we might conject that, in England, while we found examples which suggest that pedagogic work is infused across secondary school science, there may also be some particularly key points when intervention might usefully be addressed, notably in early secondary (to interrupt associations of physics with cleverness that seem to solidify particularly during this period) and through the attainment gate-keeping practice that operate at GCSE (the national examinations at age 16) and in relation to access to and retention on Advanced Level physics courses (the latter being particularly pertinent periods for young women like Kate and Davina, during which they came to see physics as being “too hard” to continue with). Based on the perceptions of students reported in this paper, there may also be value in universities considering and comparing course entry requirements between physics and other subjects, as these seemed to be implicated in self-exclusion of both young men and women from degree level physics.

Crucially, we suggest that attempts to disrupt current patterns of physics participation will necessarily have to engage with the power relations and educational structures and processes which produce the elitism of physics. That is, intervention might most usefully be directed at changing the field of physics and the physics classroom, rather than focusing on trying to change students (particularly girls), as many currently do. Although, writing in the context of science teachers, Roth et al., (2000) suggest that the habitus can be transformed in some aspects through reflective self-work, we suggest that unless the field is also changed, so as to value and align better with femininity and to challenge associations of physics with eliteness, that such work on student habitus may be limited in its effect.

So what might changing the field look like? Measures might include addressing existing gatekeeping practices to enable students with a wider range of attainment to participate in post-compulsory physics (e.g. in the UK, this might mean allowing students entry to Advanced level physics with lower attainment scores and stopping the common practice of debarring lower attaining students part way through their programmes of study), curricula (e.g. addressing issues of falsification and the perceived split between real and school physics), teaching (e.g. addressing gendered assumptions about students and the subject, challenging the notion of the effortlessly clever physicist, promoting a more gender equitable culture) and seeking to challenge the elitism and special status of physics.

We also advocate a shift in physics educational and policy discourse, so that rather than describing young women as lacking confidence in physics, their feelings of not being clever enough are understood as produced by the field and the fault of, among other factors, pedagogic work by school physics, rather than being an individualized (or gendered) lack.

Of course, the question remains as to whether physics is willing to pay the price for such changes, which would entail a loss of status and may well be anathema to those who have been through a long apprenticeship of socialisation within the subject. That is, attempts to make physics more equitable will necessarily entail some giving up of privilege, given that the elite status of the subject is produced in no small part through its alignment with cleverness and masculinity. In this respect, we might reasonably expect push back from those who are most invested in, and who occupy high status positions within the field, who currently benefit most from these associations. We consider that it is also unlikely that popular arguments from within the business case canon of discourse will have much effect on widening participation. Arguably, the subject currently tolerates a high level of wastage, in the form of the self-exclusion of highly talented students (as exemplified by girls like Kate and Davina) in the service of the reproduction of the subject's elite status. Bourdieu writes about how the imperative of social reproduction outweighs the wastage of working-class talent by the education system ("a low technical efficiency may be the price paid for the educational system's high efficiency in performing its function of legitimating the 'social order'", Bourdieu and Passeron, 1990, p. 184). We suggest that, in the case of physics, this point can be extended to the 'wastage' not just of working-class talent but of middle-class, particularly female, talent too.

To conclude, we suggest that interventions which aim to recruit more students into Advanced and degree level physics are unlikely to affect much change if the elitism of physics is not disrupted and the underlying structures and processes of inequality are not addressed. However, despite this pessimism, we suggest that approaches, which do attempt such a troubling disruption, may hold promise.

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[i] The 61 students who were interviewed came from a broad range of socioeconomic backgrounds and self-identified gender and ethnic backgrounds. 26 self-identified as male, 34 as female and one student self-identified as non-binary. 43 self-identified as White British [25 female, 17 male, one non-binary], 3 as Black British [2 female, 1 male], 5 as White European [3 female, 2 male], 6 as South Asian British [2 female, 4 male], and 4 as 'mixed' ethnic heritage [3 female, 1 male]).

[ii] One of the young men (Josh) also expressed an explicitly gender stereotypical view, aligning maths and science with masculinity: "I think it's, I believe that it's, it makes me sound sexist, but it's true when they say that women are better at English and men are better at Maths. It's not true for everyone, but in general I seem to think that's the case" (Josh, age 17/18).

[iii] Two further young women in the sample started, but did not complete, physics A level.