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PLEASE CITE THE PUBLISHED VERSION

<http://dx.doi.org/10.1093/teamat/hrw016>

PUBLISHER

© Oxford University Press (OUP)

VERSION

AM (Accepted Manuscript)

PUBLISHER STATEMENT

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Black, Laura, and Paul Hernandez-Martinez. 2019. “Re-thinking Science Capital: The Role of ‘capital’ and ‘identity’ in Mediating Students’ Engagement with Mathematically Demanding Programmes at University”. figshare. <https://hdl.handle.net/2134/21830>.

Re-thinking science capital: the role of ‘capital’ and ‘identity’ in mediating students’ engagement with mathematically demanding programmes at university

Laura Black and Paul Hernandez-Martinez

Abstract

A wide body of literature has highlighted how high achievement in mathematics in secondary school does not necessarily motivate students to both choose and succeed on mathematically demanding programmes at post compulsory level. The recent Enterprising Science project (Archer et al, 2015) and before that, the ASPIRES project (Archer et al, 2013), have both highlighted that access to science capital is perhaps more important than prior achievement in shaping students’ aspirations and their future trajectories in STEM. In this paper, we critically analyse the notion of science capital and its role in mediating students’ choice of and experience of studying mathematically demanding degree programmes at university. Drawing on data from the TransMaths project, we present two cases – Stacey and Elton – who are both enrolled on the same ‘Mathematics for Physics’ course at university. We show that although both discuss access to science capital in narrating their choice of degree, they do so in different ways and this invariably interplays with different forms of identification with ‘Mathematics for Physics’. We conclude that there is a need to re-conceptualise science capital so that the dialectic relationship between its exchange and use value is theorized more fully. Whilst some students may access science capital as a means to accumulate capital (e.g. qualifications) for its own sake (exchange value), others appear to recognize the ‘use value’ of science learning and knowledge and this produces different forms of engagement with science (and mathematics). We therefore, argue that authoring oneself in the name of a STEM identity is crucial in mediating how one perceives science capital. Finally, we argue that mathematics should be a central part of this framework since it significantly contributes to the exchange value of science as a form of capital (especially Physics) but it also offers use value in scientific labour (e.g. in modelling scientific problems).

1. Introduction

A wide body of literature has highlighted how high achievement in mathematics in compulsory schooling does not necessarily motivate students to choose mathematically demanding programmes at post compulsory level. Indeed, Riegle-Crumb et al, (2012) point out that differences in achievement do not fully account for differences in STEM career persistence by gender or ethnicity. This has led to increasing interest in affective factors such as mathematics self efficacy (Pampaka et al, 2011; Pajares and Miller, 1997), self concept (Pietsch, Walker and Chapman, 2003) and aspirations towards science (Archer et al, 2013) as potential predictors of student participation in STEM related careers.

Our own work from the Transmaths project (www.transmaths.org) has contributed to this area by specifically focusing on the role mathematics plays in accessing STEM (mathematically demanding) programmes at university. Here, we have argued that constructs such as ‘disposition towards further study’ (Pampaka et al, 2013) and the acquisition of a ‘mathematical identity’ are crucial in shaping both future STEM career aspirations (Black et al, 2010 and Black and Williams, 2013) and engagement with STEM subjects whilst at university (including ‘mathematics for STEM’ – e.g. Physics/Engineering). In this work, we have argued that mathematics plays a special role in the process through which STEM aspirations are formed since we know that success in mathematics acts as a critical filter, with students who perform poorly in mathematics in lower secondary school (age 11-14) aspiring to careers that are of lower prestige than their higher achieving peers (Shapka, Domene and Keating, 2006). Thus, we have argued that understanding students’ relationships with mathematics is crucial when exploring their participation and aspirations towards STEM at university (Black et al, 2010).

The role of the student’s social background in shaping their aspirations and relationship with STEM subjects (including mathematics) has been a key focus in the literature on how students access STEM at post-compulsory level. Previously, we have drawn on Bourdieu’s theory (Williams and Choudry, 2016) as a means to delineate how one’s social location in the structures of society are produced and reproduced through educational practices. It is through such practices that categories of class, gender, ethnicity etc. are culturally mediated, and we argue (along with

others) that forming aspirations and choices regarding one's future in education are key practices where the process of stratification is apparent. For this reason, we are interested in Archer et al's (2013) work on science capital (primarily based on their ASPIRES project and more recently, *Enterprising Science*) which, they argue, is a key factor in explaining students' developing aspirations towards a future in science and how they are mediated by social class, gender and ethnicity (Archer et al, 2015). In this paper, we examine how science capital is evident in the reflective narratives of students who have already chosen to study science (or rather what we have termed as 'mathematically demanding' subjects more generally) at university, in order to unpack how their choice of degree programme and their experience of studying science is mediated by their social background. In doing so, we adopt a critical approach exploring how the value attributed to this form of capital may be contradictory (Williams 2011, Williams and Choudry, 2016) and how this may interplay with the kinds of STEM identities we have discussed in our previous work (Black et al, 2010, Black and Williams, 2013). Therefore, this paper seeks to address the following questions: What role does science capital play in mediating the relationship between a student's background and their choice of degree programme? How does science capital interplay with a student's identification with STEM subjects when at university?

2. What is science capital?

Archer et al (2013) originally referred to science capital as "science-related qualifications, understanding, knowledge (about science and 'how it works'), interest and social contacts (e.g. knowing someone who works in a science-related job)." (p.3) Here, they particularly focused on how this may be accumulated and accessed in 'science families' (i.e. where parents hold degree level STEM qualifications, are in STEM careers and where family members have an interest in science) and suggest these then support and enhance individual student engagement and participation in science. For example, they reported that 60% of students who come from families with high levels of science capital are aspiring towards STEM related careers by Year 9 (aged 14) whereas those who have low science capital and non-STEM aspirations at age 10 are unlikely to develop aspirations towards STEM later on (Archer et al, 2013).

More recently, as part of the Enterprising Science project, Archer et al (2015) have developed science capital further as a conceptual device for collating various forms of capital, which specifically focus on science. They draw on Bourdieu's theory (Bourdieu, 1986) which outlines how individuals/groups, who have access to certain resources, networks, values in a given field (e.g. education), can access positions of privilege in so far as such values etc. are legitimated by the field. Bourdieu (1991) likens capital to playing a trump card in a card game, where those in possession of the trump card (i.e. that which ranks above other cards - capital) are more likely to win. In other words, they can exchange capital to substantiate a more privileged position in the field which necessarily involves generating further capital (capital growth). Bourdieu (1986) outlines various forms of capital which are: economic capital (financial resources), social capital (social networks and relations), cultural capital (cultural goods, resources including qualifications and dispositions) and symbolic capital (the forms of capital which hold most legitimacy in more dominant fields, such as the education system). Archer et al (2015) draw on all of these to outline science capital as consisting of: scientific forms of cultural capital (scientific literacy; dispositions towards science, symbolic forms of knowledge about the transferability of science qualifications), science-related behaviors and practices (e.g., consumption of science media; visiting informal science learning environments, such as science museums), science-related forms of social capital (e.g., parental scientific knowledge; talking to others about science).

Given that science capital is part of a wider system of capital exchange which is known to reward those occupying more dominant positions in society (Bourdieu, 1986), Archer et al (2015) suggest it is unevenly spread across social groups. They note the amount of science capital a student has access to is significantly associated with membership of: more dominant social classes (using a measurement of cultural capital such as parental education, occupations), specific ethnic groups (South Asian and White) and being male. This builds on the findings of the ASPIRES project which noted those who had strong science families were mainly middle class: "Where middle-class families possessed science-specific capital and de-ployed this within a family habitus that is both strongly "pro-science" and engaging in child-rearing patterns of "concerted cultivation" (Lareau, 2003), the result was extremely powerful." (Archer et al, 2012 p. 11). In this sense, we can see how deploying science

capital is not simply a matter of translating parental occupations into childhood aspirations (e.g. through acting as role models) but it is also an act of investment whereby parents spend time cultivating an interest in science through extra-curricular activities (e.g. visiting museums) in exchange for further deferred capital for their children (e.g. an academic ability in mathematics/science). Here, science capital is defined by its exchange value (i.e. its power to grow capital) which itself is defined by what is given value in a particular field such as education.

In this paper, we look for evidence of science capital in the narrative interviews we conducted with students as part of the Transmaths Project since it provides important conceptual tools which enable us to understand how relations of social class, gender and ethnicity are made present in the education field through access to and exclusion from STEM subjects. Particularly, we appreciate Archer et al (2014)'s recognition that science capital has both exchange value and use value in terms of its status as culturally valued knowledge which supports individual participation and engagement with STEM subjects. This will be an important consideration in our analysis below. However, there are also a number of key points of departure between our 'Transmaths' approach and that of Archer et al (2013, 2015) which we now discuss. We do so in order to develop the concept of science capital further as an explanatory framework for investigating student trajectories into STEM subjects at university.

3. The Significance of Mathematics

As highlighted above, our 'Transmaths' research has emphasised the significance of mathematics in mediating both access to STEM university degree programmes/careers and participation/engagement in STEM activity (i.e. doing science). However, student access to and use of mathematics is given little attention in Archer et al's (2015) account of science capital, which, we argue, is a significant omission. In this paper, we argue that success and engagement with mathematics is highly relevant to our investigation of science capital for two reasons: (i) mathematics forms a key part of 'science' in the broadest sense - a view shared by many who work in STEM professions who do not differentiate between the sharp subject boundaries of the school curriculum (Sheldrake et al, 2015). In this sense, we argue that mathematics has use value in terms of its application in scientific labour which then adds exchange value to the production of scientific commodities (Williams 2011) and

(ii) 'ability' in mathematics acts as a gatekeeper to many STEM careers and therefore, it is an essential part of the exchange process through which access to science capital becomes a STEM aspiration and a realistic possibility for students. For instance, students' decision making about subject choice (e.g. at age 14) both at compulsory and post-compulsory level must at some stage include reflection on one's ability in mathematics if one wishes to pursue a future that is STEM related. Our own work here highlights how student perceptions of the connection between studying school mathematics and aspiring towards a STEM related career can take different forms – with some recognising the exchange value school mathematics offers (as a gatekeeper) (Hernandez-Martinez et al, 2008) and others recognising its use value in terms of imagining how it might be re-contextualised in a workplace or professional role (Black et al, 2010).

4. The significance of STEM identities

A key finding from the ASPIRES project is that whilst many students see science as potentially useful for a future job, far fewer see such jobs as personally relevant or achievable (Archer et al, 2013). We would argue that this emphasis on personal relevance demonstrates the significance of students' identification with STEM subjects (e.g. engineering – Black et al, 2010) and the role of an imagined future in a STEM career (Williams et al, 2009). Thus, we hypothesise that developing an identity or identification with STEM is as important as accessing science capital in shaping aspirations and we need to understand the inter-relation between these two, particularly if we are to unpack the family and school related practices which mediate them. More recently, Archer et al (2015) have introduced the notion of a 'science identity' into their conceptualisation of science capital but this differs from our account in significant ways. Firstly, they refer to a science identity as believing one is 'seen as a science person by others' whereas we emphasise one's personal investment towards an imagined future which may provide a motive for studying STEM (see Black et al, 2010). For us, awareness of how others may see us remains crucial to our concept of identity, but we also emphasise the motive that such an identity can offer in terms of how we perform that identity in practice (see below). Secondly, we wish to maintain a distinction between a STEM identity and science capital in order to highlight that personal investment in a STEM career is needed for the accumulation of

science capital (in its embodied form). Therefore, we suggest that identity mediates the acquisition and exchange of science capital in a dynamic way.

Our emphasis on identity here draws on Holland et al's (1998) notion of 'identity in practice', which defines an identity as a culturally reified form (e.g. I am a maths person or I want to become a Physicist) which is constructed through engagement in socially mediated practice (e.g. mathematics learning activities). Subsequently, once we have mobilised ourselves in the name of an identity, this becomes an intensifier of engagement in the relevant practice which then further strengthens the identity (e.g. I am good at mathematics, I will do hard mathematics and so on). Like Holland et al (1998), we see capital as highly relevant, but not reducible to, our capacity to perform this 'identity in practice' as it enables one to position oneself in particular ways in a given field (referred to as a 'positional identity'). Thus, the student with access to science capital may be able to use such capital to position themselves as a particular kind of student (e.g. brainy) which they then perform in the classroom (strengthening this identity). However, we have also seen cases where students imagine themselves as a future scientist without access to the capital required to achieve this (see Williams et al 2009). Thus, again, we argue that a conceptual distinction should be made between a STEM identity and science capital in order to explore the dynamic relationship between locally produced cultural forms and structural relations of dominance in the education field (see Choudry and Williams, 2016).

5. Context, Methodology and Findings

The Transmaths project involved interviews with 50 students at three different data points – i) near the beginning of their university degree programme (or in the summer just prior to this), ii) at the end of Year 1 and iii) during Year 2. The interviews adopted a narrative biographical approach which began with an open question 'Tell me how you came to be a student on this degree programme' and then asked more probing questions regarding relevant themes such as: reasons for choosing their degree programme, aspirations for future study/careers, experience of university teaching, and whether they perceived their gender/ethnicity/social class to have had an impact on their trajectory into university and beyond. To analyse this dataset, we compiled short biographical summaries for each student in order to explore how each case connected to our theoretical understanding of identity and the practices which

mediate identity formation. The stories of Elton and Stacey are particularly interesting to compare because both students attend the same Physics degree programme at the same Russell Group university (Northern). We have opted to discuss these two students in this paper because they provide a useful contrast in terms of how they discuss their access and use of science capital and how this connects to a STEM identity (or rather Physics identity) of some sort. Below, we provide a narrative analysis of their data using the interviews conducted at all three data points. To construct each narrative, we have read each interview transcript looking for comments that appear to operationalize the key concepts we have identified above: science capital, cultural capital and identity. We have then used such comments to build the narrative analysis denoting the relevance of science capital and cultural capital to each student's account of how they became interested in Physics and/or why they chose to study this subject at university. Furthermore, we explored the kinds of identity they narrate in terms of identity statements (I am x, I hope to be y) which indicate their positioning as a student at university and their future employment trajectory.

In conducting this analysis, we are mindful of the somewhat unique context of the interview scenario where students are asked to reflect back on their prior experience and decision-making and construct a narrative about themselves for the benefit of the interviewer. Elsewhere we have suggested this activity involves a special kind of identity in practice where one reflects on other identities in practice (e.g. as a mathematician, a Physics student, a son/daughter) and tries to make some kind of coherent sense of this multiplicity (forming a narrative identity) (see Black & Williams, 2013). However, it is important to note that such narratives are sometimes unstable (particularly from one interview to another with the same student) and on several occasions in our wider analysis of this data, we noted that students were changing the way they presented specific events or meanings from one interview to another. This does not mean our analysis lacks validity but rather that we should be mindful that references to science capital etc., whilst drawing on students' experiences outside of the interview context, are also produced as part of the interview activity.

5.1 Elton's story

Elton described to us a highly privileged family background with an abundance of social, cultural and economic capital circulating in his family network. His father has worked as a Stockbroker in the City (London) for 25 years and his mother gave up working as a cook when he was a child but has since worked on some major domestic projects such as designing and building their family home. Elton spent most of his childhood at boarding school only living at home for short periods of time which he believes has aided his transition to university:

“I never lived at home for a consistent long period of time, for more than 3 or 4 weeks since I was 8. So coming to university wasn’t exactly too difficult a transition from living away from home.”

He had also undertaken a gap year prior to starting university which involved extensive travel (funded by his parents) plus work experience in the City:

“It helped educate me in a sense, I had a lot of fun, but I also know a bit more what I want to do, away from sheltered boarding school cocoon and know what its like in the real world, to have a job in London, to have a couple of jobs in London, to travel around the world and see everything, the good things the bad things.”

The decision to attend university was, for Elton, largely pre-determined by his parents:

“They came to regard that everybody these days in our social surrounding goes to university, there are very few that don’t and there is also the fact that you aren’t taken seriously in the job market, at 18 if you don’t have a degree people ask why don’t you have a degree? – it’s a big taboo. So I definitely had no choice but to go to university”.

In sum, Elton’s account of his family background details the circulation of cultural and economic capital by the family (e.g. providing working experience or paying for boarding school) which can then be exchanged for further capital (e.g. by enabling their son to go to a ‘better university’ studying for ‘a highly regarded degree’ (Physics). Elton’s feel for the game (*illusio* – Bourdieu, 1996) is highly explicit in his interview where he talks about ‘working the system heavily in his favour’ – his decision to study Physics was shaped by the fact that it is seen as prestigious but demanded lower grades than other subjects (e.g. his preferred choice of Politics, Philosophy and Economics) because participation rates are low (as he perceives it).

Amidst all of this, Elton spoke of his access to science capital which had, in part, shaped his choice or interest in studying Physics. In terms of social capital, he had gained work experience in the bio-fuel sector during his gap year which was aimed at “getting a job... in that sector” and he saw this as “very linked to Physics” as it involves ‘alternative energies’. Furthermore, he also spoke of how his access to wider cultural capital (i.e. boarding school) had mediated his access to ‘an inspirational physics teacher’ who motivated him to choose the subject (i.e. talking to others about science – Archer et al 2015):

“He helps write the A level Physics papers, he just gets extremely over excited about Physics almost like a kid with ADHD. He gets very overly excited and it can be quite funny to watch him but, you know, if you’re on the same line as him it makes the subject very fun.”

So whilst it appears that Elton does not specify all the components of science capital outlined earlier, it is clear that there is some circulating within his social network and that this is part of a wider system of cultural and social capital exchange that students who come from this kind of privileged background have access to. Particularly, Elton’s awareness that a Physics degree has exchange value in terms of getting a good job indicates his awareness of this system of exchange (symbolic capital). He believes that studying Physics will “prove he’s clever” and that he is “able to solve real life problems”. Yet despite this, he states that in the end his future will not be in Physics:

“You do what pays and what pays is not Physics as such.... they know that physicists are very, very good at mathematics so if the banks and the finance sectors were willing to pay more then that’s what people will do.”

In this sense, we can argue that whilst Elton discusses some science capital in presenting his biography, he focuses on its arbitrary function as a means to access his university Physics degree in order to mark him out as ‘clever’, which will then be rewarded with ‘more pay’. Thus, he focuses on the exchange value that his science capital offers which arguably, enables him to take up (reproduces) his privileged position in the field. However, in doing so, Elton does not mobilize his science capital towards a particularly strong identification with Physics (which for him is ‘working mathematically’). In fact, in Elton’s account he juxtaposes ‘other’ people who are good at Physics with his aspiration to get a good job:

“I would say that a lot of the really, really good people at Physics are mildly autistic. Erm, in the sense that they have a brain, which works very well

mathematically and then they look at, when they look at a diet coke machine, ... they can see how it works straightaway, erm, and they can, they can write it down, unfortunately for them they don't always have the social skills required for the workplace.”

Elton's comments here resonate with the 'brainy' image of science which DeWitt et al (2013) identify as a deterrent to participation in the sciences (especially Physics which was seen as 'only for the clever'). Thus we can say that Elton does not see himself as a physicist because this implicates a lack of social skills, which he feels are important in the workplace. In fact, Elton states that his “true” interests (identity) lie in Politics or Economics: “[it] really, really fascinates me and I read a lot of the news” but again this interest is juxtaposed with the arbitrary exchange value he believes his degree should offer which is the main purpose behind going to university.

“I don't need to take three years off to sort of enjoy, effectively study something that I enjoy. Does that sound quite strange to you? [...] I will read them [newspapers] anyway, you know, outside of my course. [...] I've come here to learn something, erm, so that I can get a degree, which the job market thinks is more worth while.”

As the interviews progressed, it became clear that Elton's somewhat negative identification with Physics was associated with troubles he was experiencing on his course. He reported that he lacked the self direction required at university (e.g. “if I don't turn up to a lecture no one is really gonna notice”) and struggled to motivate himself to get the work done. At the end of his first year at university, Elton reports having had to re-sit several course units because he has failed them, and he associates his poor academic performance with his lack of interest in Physics. He struggles to see the relevance of what he is learning to 'real life': “I would say there's also large....proportions of it that I'm just, like, why am I sitting here listening to this? This is most irrelevant to later in life.” Furthermore, Elton's rather negative relationship with mathematics seems central to his dis-identification with Physics. In our first interview (i.e. before any problems with re-sits arise), Elton reports that he is struggling with mathematics and he attributes this to a) his gap year which means he has not studied any mathematics for 15 months and b) difficulties he experienced learning mathematics at A-level: “...had to put a lot of effort in at A level to get a B”. This has resulted in a sense of “I'm not clever enough for this course...because it's a difficult course, and my maths isn't... amazing”.

To summarise, we suggest that Elton's focus on the arbitrary exchange value that his science capital engenders does not offer a sufficient motive to keep him engaged with studying Physics, particularly when troubles are encountered. In fact, his negative identification with studying Physics seems partly mediated by a desire to distance himself from what might count as capital on his Physics course (i.e. having a mathematical brain but no social skills). As such, Elton's account appears to expose the contradictory nature of science capital whereby its exchange value i.e. providing access to 'a good degree from a good university' is juxtaposed with the use value of scientific knowledge and learning (e.g. in pursuing activities for personal interest). Without recognizing the use value of what is learnt that goes beyond the arbitrariness embedded in its exchange value (in terms of gaining employment), Elton becomes disengaged (Williams 2011). He then positions mathematics as a filter mechanism which separates him from those who are good:

"If I can just ... scrape by with a 2:2 or a third, erm, ... I don't have the motivation, which I already have if I'd done a degree, like, History or Politics ...but I know that that is not even close to realistic with my mathematical ability."

5.2 Stacey's story

In contrast with Elton, Stacey spoke of a long term desire to study Physics which stemmed back to her childhood and an early interest in Space.

"I had a keen interest in like the solar system. And I was told you'd learn more about that in Physics, and I was like, right I'll do Physics then. So, I've loved it ever since."

As such, there is a strong element of science capital in her narrative which includes having access to resources ("I had like a huge mural on my wall, so many books it's ridiculous") and a positive relationship with her father who is an engineer on an oil rig (social capital): "Well my dad's an engineer so it came from that. He was always watching Science documentaries and stuff" (i.e. consumption of science media). In addition, Stacey also recognized that her family's influence (as a form of social capital) was crucial and quite unusual:

"I think it's also weird because I live right next to a huge industrial state, I mean, there's a nuclear power station just down the road, you'd think if

anything you know, nuclear power - that would get people interested, but it just doesn't. I don't know why I, I mean, obviously the family got me interested, but I don't know why other people don't get interested."

Furthermore, like Elton, this science social capital inter-plays with other non-science aspects of cultural capital such as her parents aspirations for her to attend university: "They've all, they've been saving since before I was born for me to come to uni."

However, unlike Elton – Stacey narrated a strong identification with Physics as is apparent in her comment above: "I've loved it ever since". This suggests she perceives her current position studying Physics at university as the culmination of lifelong ambition. Furthermore, she described herself as 'always a Science geek' and spent much of her interview discussing 'really interesting' documentaries and books about Physics she had seen/read recently.

The strength of this Physics identity also seems to have helped Stacey deal with uncertainty and ambiguity and she recognizes that this must be negotiated as part of the course of becoming a physicist.

"I mean some of the stuff, I mean, some of the lectures, they're like, "this relates back to the big picture"" and it's still kind of hazy so you can't really see the big picture there, but you kind of - you know that it's there, you just can't see it yet, so you're just trying to find it."

As such, we might argue that Stacey's identification as a Physics student involved enjoyment and interest and a belief in 'playing the game' for its own sake rather than merely to achieve a particular qualification. In this case, the use value of Physics is manifest in Stacey's consumption of the subject (satisfying her interest) and in this case, such perceived use value does not contradict the exchange value her science capital has provided in the past (in enabling access to university Physics) and in the future (her Physics degree) i.e. she feels rewarded for doing what she loves.

As in Elton's case, mathematics is also a critical part of the story here in that Stacey's relationship with mathematics mirrors the relationship with Physics described above.

I: You didn't think of doing maths as a degree though?

Stacey: I considered it and I was actually better at maths than I was at Physics.

[...] But I just thought, you know, Physics kind of puts stuff into perspective, I dunno. Yeah.

I: In perspective?

Stacey: Yeah, I dunno, it's just kind of, it gives it more oomph!

In fact, at this stage, for Stacey mathematics is strongly embedded in studying Physics to the extent that it shapes the way she sees the world (use value):

“And then a lot of Physics is maths as well.[..] ‘Cos we do like, mechanics is in Physics, which I count as maths, but apparently Physics counts it as Physics which probably makes more sense actually but, yeah.[...] its interesting to see the world, the way the world works and stuff like that and why things react the way they do and I think that's all mechanics really.”

6. Discussion

In presenting this analysis, we argue that our data resonates with the findings of both ASPIRES (Archer et al 2013) and Enterprising Science (Archer et al, 2015) in that it highlights the presence of science capital in the biographies of students studying science (Physics) at university. In the above analysis, both students discuss their access to science related social capital (i.e. others with scientific knowledge like parents or an inspiration Physics teacher) and they also discuss in various ways access to symbolic forms of knowledge about the transferability of science qualifications (Elton) and their consumption of science media (Stacey). However, there are also a number of issues raised by our analysis which are not accommodated by Archer et al's (2015) science capital framework as it currently stands. Therefore, we argue, the framework requires additional explanatory concepts in order to explain the function of science capital in mediating student participation and engagement in science.

Firstly, our reading of Bourdieu pays particular attention to the arbitrary nature of capital which stems from its exchange value in relation to the field. This was apparent in Elton's story where his account of science capital has no real purpose but to be exchanged for a higher status degree programme or a better job. As noted above, this does connect to Archer et al's (2015) argument that symbolic capital ('symbolic forms of knowledge about the transferability of science qualifications') should be a central concern in any consideration of science capital. However, it does seem that

their framework pays little attention to the cultural arbitrariness of capital, and its function in establishing and producing power relations of dominance/dominated associated with social class, gender etc. Hence, Elton presents his Physics degree (and prior science capital) as marking out his 'Distinction' (Bourdieu 1984) in the labour market as a means to produce and reproduce his privileged position (capitalizing on previous capital investment e.g. at boarding school). This means that access to such capital cannot simply be distributed more widely to increase access to science for all (c.f Archer et al's (2013) argument for 'building science capital') because, as Bourdieu notes, it serves a function in reproducing classed, gendered, ethnic relations in society.

Elsewhere we have also argued for a more dialectical understanding of capital which recognizes the contradictions between exchange and use value inherent in learning and labour power. As Williams and Choudry (2016) and Williams (2011) note, for knowledge and learning to be exchanged as a commodity it must have some use value in terms of eventual consumption by society (in what we have called scientific labour). Here, we argue that the arbitrariness of Physics as a 'brainy' subject exposes this contradiction in that it provides cultural exchange value to those who can access it (as a form of selection and exclusion) – access which as, DeWitt et al (2013) note is highly gendered and probably classed. Yet this 'brainy image' perpetuates science as a relatively scarce form of knowledge inaccessible to the many: it serves only to enhance the power of those in the know, while impoverishing those who are excluded. As such it serves no 'useful' function, except the reproduction of relations of dominance in the field. Therefore, even Elton as a white, privileged male, finds it difficult to identify with being 'brainy' (and its emphasis on individualism) if one identifies as sociable. Although, ironically, for those who 'see' science beyond the cultural arbitrary and the exchange value it offers, being social is in fact a necessary part of engaging in the collective labour required to create commodities which have some use value.

Secondly, in making this argument, we also go beyond Bourdieu (as per Holland et al 1998) to argue that a concept of 'identity in practice' is necessary for explaining how and why students may engage with the use value of science. In Stacey's story, we see how she narrates a strong 'Physics student identity', which emphasises enjoyment of

Physics for its own sake rather than merely for the exchange value it offers. This then resources her capacity to deal with not knowing and not understanding since this is part of what it means to study Physics at university whereby one imagines future application of what is learnt in a STEM career (the ultimate exchange or reward for the use value of scientific labour power). Stacey's story here resonates with our previous work (Black et al, 2010, Black and Williams 2013) where we have argued that identifying with this use value 'in practice' is important in explaining student engagement. This finding conflicts with Archer et al. (2013), who state that whilst many students are interested and enjoy science in school, they do not aspire towards careers in STEM professions. Consequently, they sideline student interest and enjoyment of science in their conceptualization of science capital. By contrast, we argue that such interest (and associated identification with science) is central in explaining why some students are able to 'see' beyond science as an arbitrary form of capital.

Finally, we also argue that mathematics is a critical part of the story here since this also contributes to the contradictions between exchange and use value inherent within science or STEM learning as identified above. In Elton's story, studying mathematics is about getting the grades or getting the knowledge, which will enable him to maximize the exchange value of his degree. In this sense, 'being brainy' at mathematics adds to the braininess of Physics (or science more generally) and hence to the exchange value it offers. But as we have argued elsewhere (Black et al, 2010), mathematics also offers use value to the sciences which has important implications for how we position the relationship between mathematics and the other sciences in the educational field. For instance, Stacey sees mathematics as deeply embedded in the Physics she loves and so it has use value in enabling one to see the world in a particular way. This resonates with a large body of work on 'modelling' as a powerful example of how the use value of mathematics can be fostered in pedagogic/mathematical practice (Williams and Wake, 2007; Wake this issue). Therefore, we argue that the omission of mathematics from Archer et al's framework is problematic, since if we are to develop pedagogic practices which address the structuring effect of science capital then challenging the 'gatekeeper' positioning of mathematics in relation to science is fundamental.

Our argument here has key implications in terms of how to challenge the arbitrariness inherent in the teaching and learning of science and mathematics in schools and at university. Elsewhere (Hernandez-Martinez and Pampaka, accepted) we have argued that practices which focus on ‘teaching to the test’ (exchange value), dominant in so many schools (and universities), can have a negative influence on students’ dispositions to study more mathematics thus alienating them from a future in STEM. Therefore, we argue that there is a real need to move away from teaching and institutional practices which emphasize the arbitrary forms of exchange value (e.g. attainment scores) which appear to be at play in our analysis of science capital above. This is at odds with one of the recommendations of Archer et al (2013) which focuses on strengthening science capital ‘for all’ by raising awareness of the exchange value of a science degree. Instead, we argue for a conceptually coherent programme of change in schools and universities, whereby the use value of science (including mathematics) is promoted and aligned (rewarded) with exchange value. Thus we argue for a critical pedagogy whereby the kinds of knowledge, which might be more productive for social purposes in the community as well as provide for more productive labour, can engender exchange value for students (via accreditation, or even such schemes as the educational maintenance grant). Thus, whilst we do not necessarily oppose the various dimensions which encompass a ‘science capital approach’ (Archer et al. 2016) (e.g. they propose a more engaging approach which emphasizes science in everyday life), we argue for an approach which is more theoretically grounded. For us, this means trying to identify use value in what is learnt and reward it with credit/knowledge (exchange value) whilst also creating critical awareness of the ultimate exchange value of such knowledge in terms of one’s career or contribution to wider society. Therefore, the proposal to integrate careers information into the curriculum is good if this is broad and counters the ‘brainy’ and exclusive image of science (and its function in terms of social stratification) at the same time.

Acknowledgements

The TranMaths Project was funded by the ESRC (RES-062-23-1213) and we are grateful to the TransMaths research team for their work in collating data, analyzing and theorizing which underpins this paper.

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