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Becoming exceptional: the role of capital in the development and mediation of mathematics identity and degree trajectories

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Abstract
There is a burgeoning interest in the concept of identity within mathematics education research, with recent work suggesting that the interplay of identity and capital (cultural, social, and economic resources) offers a productive lens for understanding school students' trajectories into, or away from, mathematics. This paper adds to understandings of how interactions of identity and capital play out over time, focusing on how these mediated the mathematics degree trajectories of three young men, Tom, Neb, and Gerrard, who were selected from a wider longitudinal study, as the only young people who went on to take mathematics degrees. Analysis of longitudinal data from 24 semi-structured interviews, conducted with the three young men from age 10 to 21 and two of their parents/carers, found that all three identified as being "good/exceptional at mathematics". These identifications developed at an early age, were sustained and augmented by capital, and were closely related to pursuing the subject at university and enjoyment of mathematics. However, developing and sustaining an identity as "good at maths" relied on interactions with mathematics capital through families, school, and wider networks. Moreover, classed differences in the distribution of capital were implicated in their different degree outcomes. We argue that attending to the longitudinal interplay between capital and identity offers a rich understanding of how young people come to see themselves and be seen by others as "naturally able" at mathematics and in turn supports choosing to study a mathematics degree. Implications for mathematics education policy and practice are considered.

Keywords Identity · Capital · Mathematics degree · Longitudinal · Participation

1 Introduction

In this paper, we are interested in how the interaction of mathematics identity work and capital offers a lens for understanding and explaining mathematics degree level trajectories. Existing research has found that attending to the interplay between identity and capital can

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provide a productive lens for understanding school students' engagement, participation, and trajectories into, or away from, STEM subjects such as mathematics (Black & Hernandez-Martinez, 2016), science (Archer et al., 2023a, 2023b, 2023f), computer science (Holmegaard et al., 2024; Archer et al., 2023d), and engineering (Archer et al., 2023c). This paper builds on and seeks to extend these insights through an empirical contribution that (i) focuses on students studying for a degree in mathematics and (ii) undertakes a longitudinal analysis of how identity and capital interact over time within a young person's mathematics trajectory. Through longitudinal case studies of three young men who were interviewed from age 10–22 and who each went on to study mathematics at degree level, we examine how they developed, performed, and articulated mathematics identities over time and the role of capital in mediating this identity work. While there are a couple of existing studies that consider the development of mathematics teacher identities over time (e.g., Lutovac and Kaasila (2018) interviewed a Finnish primary school teacher at two time points, a decade apart, to explore his account of his mathematics teaching, and Machalow et al. (2020) conducted a quantitative study of teachers' shifting identities from learners to teachers of mathematics), to our knowledge, there are no existing longitudinal studies of mathematics *students*' identity development over time—hence, the paper seeks to offer a new empirical contribution in this respect.

Prior research has noted how identity and capital are mutually mediating phenomena within young people's STEM engagement and trajectories, with identity mediating the acquisition and exchange of capital (Black & Hernandez-Martinez, 2016) and, in turn, possession of particular forms of disciplinary-specific capital mediating the acquisition and development of a STEM disciplinary identity (Archer et al., 2023a, 2023b, 2023c, 2023d, 2023e, 2023f; Holmegaard et al., 2024). This literature reveals how identity and capital are intricately entwined and recursively linked phenomena that mutually mediate their respective functioning in ways that influence student participation and engagement in STEM fields. As there are various conceptual approaches theorising both identity and capital, below we explain and situate the ways in which they are used in this paper. We begin by reviewing the literature pertaining to mathematics identity, as this is a relatively commonly used concept within mathematics education research. We then move on to consider the smaller body of work that has considered the interplay of identity with capital in shaping young people's mathematical (and STEM) trajectories, which informs the conceptual basis of this paper.

2 Identity and mathematics trajectories

Identity is a relatively widely used concept within mathematics (and also science, e.g., see Holmegaard & Archer, 2023) education to understand how learners and teachers engage with the subject. Indeed, Chronaki and Kollosche (2019, p. 457) note the "explosive interest" in identity in mathematics education research. For instance, work has focused on how identity is implicated in learning mathematics (Radovic et al., 2018) and in the reproduction of inequalities in participation and attainment by gender, race, and social class (e.g., Black et al., 2010, 2019; Boaler & Greeno, 2000; Hazari et al., 2020; Martin, 2000; Morton & Parsons, 2018; Nasir, 2002; Nasir & Cobb, 2007). As Bartholomew et al., (2011, p. 915) argue, "choosing particular subjects is closely bound up with an individual's sense of self – the kind of person they see themselves as being and present to the world".

The concept of mathematics identity/ies has been developed within a range of theoretical frameworks (e.g., see reviews by Darragh, 2016, and Radovic et al., 2018), to capture the shifting and socially embedded ways that people relate to mathematics (Cobb, 2004; Cobb & Hodge, 2011), although arguably sometimes with a lack of specificity (Radovic et al., 2018). As Chronaki and Kollosche (2019) note, while there are a number of studies (such as some of our own prior work, e.g., Mendick, 2005, 2006) that use post-structural or cultural theoretical approaches to understanding mathematics identity, it has been more common for mathematics education research to use more psychological approaches in which identity is operationalised quantitatively through more fixed attitudinal and/or personality variables. As Chronaki and Kollosche (2019, p. 458) argue:

> Whilst such approaches have been methodologically appealing as they tend to operationalise the concept of identity easily, they often reduce it to discrete individual or group identity categories (e.g., gender as male or female, race as black or white, learner as able or unable).

In contrast, poststructural and cultural approaches provide a richer and more nuanced understanding of how relating to and engaging with mathematics requires multifaceted identity "work" by learners. For example, research by Gholson and Martin (2017, 2019) has illuminated how relating to mathematics and taking up (or resisting) a "mathematics identity" is a socially embedded, culturally bound, performative process that can be made and re-made from moment to moment both within and across contexts. Their studies of Black African American girls' mathematics engagement show how conceptions and performances of being "smart" at mathematics were mediated in multiple and different ways between different students. For instance, in their analysis of a middle-school student who found mathematics painful, Gholson and Martin (2019, p. 391) intricately detail how, for this Black young woman, "mathematics learning involves a repertoire of performances – including cool pose and blackgirl face – requiring forms of relational labor to simultaneously negotiate race, class, and gender".

The poststructural approach adopted by Valoyes-Chávez and Darragh (2022, p. 372) highlights "the strategies that students from marginalized groups use to process and respond to discouraging classroom experiences", which the authors connect to racialized emotions and identity work. By focusing on identity as a negotiated and socially/culturally situated ongoing process, rather than a fixed, enduring state or characteristic, they draw attention to the role of learner agency, arguing that this is particularly important given that:

> Mathematics education research often denies agency to oppressed and marginalized people, advancing rescuing-type narratives (e.g., white saviorism and colonial condescension) rather than solidarity. The articulation of identity work and (racialized) emotions allows the acknowledgment of people's agency and leads to different forms of organization in the struggle against oppression. (Valoyes-Chávez & Darragh, 2022, p. 372)

In this paper, we adopt a sociocultural approach (Atweh et al., 2001), in which we are interested in how identities are socially produced and negotiated (Radovic et al., 2018). Thus, we treat mathematics identity not as a fixed psychological "thing" but as a construct that is always relational and in a process of "becoming". However, our interest in the performative, agentic, and discursive nature of identity work is also tempered and held in balance by a recognition that agency is structured by and situated within relations of power and injustice. That is, as discussed further below, we understand identity work as being mediated (both opened up/made possible and closed down/made impossible) by intersectional power relations and access to and translation of capital.

Moreover, we take the position that mathematics identity work (that is, negotiating the relationship between self and subject) involves both a dimension of personal investment (and/or resistance/distancing, see Black & Hernandez-Martinez, 2016) in relation to mathematics *and* a dimension of recognition, notably the extent to which one is recognised, or not, by others as being "good at maths" and the extent to which dominant mathematics constructions, practices, and relations support or exclude particular (racialised, classed, gendered, etc.) learners from a legitimate mathematics identity (e.g., Gholson & Wilkes, 2017; Martin, 2000; Morton & Parsons, 2018), which in turn often requires considerable negotiation and identity work to navigate (e.g., Ibourk et al., 2022).

3 The interplay of identity and capital within mathematics trajectories

Bullock (2018) makes a case for using intersectional approaches in critical mathematics education research and approaches that go beyond a focus solely on identity, to take account also of the structural, discursive, and institutional influences on mathematics engagement and trajectories. In this respect, like others, we have found Bourdieu's work (e.g., Bourdieu, 1984; Bourdieu & Wacquant, 1992) particularly helpful for foregrounding the role of structural inequalities and understanding the power of social reproduction in producing and sustaining enduring inequalities in mathematics participation that are resistant to change. For instance, studies using this theoretical framework have drawn attention to how processes of socialisation and particular disciplinary practices, enacted through pedagogic work in schools (Archer et al., 2020), shape the possibilities for students' identity work in relation to STEM subjects and the role of dominant norms, values, and practices within educational fields which produce racialised, classed, and gendered patterns of STEM participation (Jorgensen et al., 2014).

Like others (e.g., Black & Hernandez-Martinez, 2016), we consider Bourdieu's concept of *capital* to be highly useful for understanding learner engagement with mathematics. Bourdieu (1984) theorises capital as cultural, social, economic, and symbolic resources, the value of which is determined by the field (the sociocultural context of power relations which define what, and who, has value in a given space) in which it is located. That is, capital does not have an inherent value in and of itself that endures and transcends space and time, rather its value is determined by the culturally, socially, and temporally situated field in question. In this way, the value of capital will change over time and context and the structure of capital represents the "immanent structure of the social world" (Bourdieu, 1986, p. 242). Indeed, he argues "it is one and the same thing to determine what the field is, where its limits lie, etc., and to determine what species of capital are active in it, within what limits, and so on" (Bourdieu & Wacquant, 1992, pp. 98–9). Hence, a key way that dominant groups maintain and reproduce their social, cultural, and economic privilege and power is through the differential valuing of capital within fields, whereby the most valuable forms of capital are recognised as being those most closely associated with and possessed by the dominant. As Bourdieu explains, a particularly effective technology of social reproduction is the naturalisation of the differential ascription of value within a field through symbolic violence, which he explains as the "violence which is exercised upon a social agent with his or her complicity" (Bourdieu & Wacquant, 1992, p. 167). In this way, the privileged attribute their dominant position to "natural talent" and aptitude (rather than their possession and deployment of the most valued forms of capital) and the oppressed come to accept their disadvantaged positions as due to their own failings (rather than their disadvantaged social position and restricted access to symbolic forms of capital within a game in which the dominant control the rules and ascription of value). Applying these ideas to mathematics, Williams and Choudry (2016, p. 3) argue that "school mathematics provides capital that is finely tuned to generationally reproduce the social structures that serve to keep the powerful in power, while ensuring that less powerful groups are led to accept their own failure in mathematics".

As Bourdieu (1986) also discusses, agency requires capital and the field shapes the possibilities for recognition of particular (socially and culturally situated, e.g., gendered, racialised, classed, etc.) forms of capital and habitus—or, extending his ideas, we might reframe the latter in terms of identity/identity work. We note here that we deviate from Bourdieu's framework by using the more agentic notion of identity/identity work, rather than his own more structured concept of *habitus*, which Bourdieu treats as a more stable and durable framework of dispositions, inculcated through socialisation (see Archer et al., 2023a, 2023b, 2023c, 2023d, 2023e, 2023f, for a fuller discussion on the theoretical reconciliation of our usage of identity and habitus).

Bourdieu was primarily interested in the exchange value of capital and the extent to which its differentially classed possession and deployment translates into the social reproduction of relations of advantage and disadvantage in fields such as education (Bourdieu & Passeron, 1979). Accordingly, a number of studies have examined the ways in which the differential distribution of exchange-value forms of STEM-related capital is implicated in the production of dominant patterns of participation in STEM by social class, race/ethnicity, and gender. For instance, studies focusing on the interplay between identity and capital have found that the extent of alignment (or disconnect) between learner identity work, mathematics-related capital, and the field of STEM education (whether experienced and practised within the classroom or more widely) can help explain different patterns in school students' engagement, participation, and trajectories into, or away from, mathematics (Black & Hernandez-Martinez, 2016). Similar findings have also been noted in relation to science (Archer et al., 2023a, 2023b, 2023f), computer science (Holmegaard et al., 2024; Archer et al., 2023c), and engineering (Archer et al., 2023d).

Likewise, Quaye and Pomeroy (2022) employ a Bourdieusian conceptual framework to look at attitudes towards mathematics between parents and children. Their quantitative study, conducted in three secondary schools in England, highlights the intergenerational reproduction of attitudes towards mathematics and achievement in mathematics. The analysis found that students from middle-class families had a more positive disposition towards mathematics than their working-class peers and that such dispositions were reproduced across generations. Indeed, parents' attitudes towards mathematics were found to account for "approximately 40% of the variance in students' achievement and attitudes towards mathematics" (p. 170). While the study does not elucidate the mechanisms through which parental mathematics dispositions are reproduced within the habitus of children, Bourdieu's wider work (e.g., 1984) points to the embedding of more durable dispositions through repeated, immersive socialisation over time within the family unit (see also Williams & Choudry, 2016, p. 7, on how "a mathematical habitus initially forms through 'mathematical' experiences with parents and siblings, and thereafter in classrooms with teachers and peer groups in schools" and Archer et al., 2012, on the cultivation of science identity through interactions of family habitus and capital).

In addition to work on the role of exchange-value capital within the social reproduction of inequalities in STEM participation, scholars have drawn attention to the importance of capital that exists within marginalised communities and which has intrinsic and local exchange value (that may, or may not, be translated into positive outcomes within dominant fields), which challenges mainstream deficit-based understandings of excluded communities as "lacking" capital (e.g., Skeggs, 2004; Yosso, 2005). Research by critical mathematics education scholars has also drawn attention to the processes through which learners might be able to develop capital with both local exchange value and wider exchange value across different fields. For instance, Hernandez-Martinez and Williams (2013, p. 49) found that:

> students can develop capital through reflection, particularly in critical moments. It is that capital that allows fore agency in new fields (for example, during transition), and the possibility to exercise that agency, negotiating successfully (aligning) their habituses with the conditions of the new field (resilience).

Despite some criticisms of aspects of Bourdieusian theory and Bourdieusian conceptualisations of capital, as Williams and Choudry (2016, p. 3) conclude, Bourdieu's work is generally useful for critical (mathematics) education research given its capacity for "exposing the interest of the dominant classes" and "researching critical pedagogic alternatives that challenge orthodoxy in educational policy and practice both in mathematics education and more generally". In this paper, we employ the concept of capital in conjunction with identity to help understand the socially patterned way in which more privileged learners (e.g., in terms of gender and class) are more likely to possess and deploy capital that supports the development and sustaining of an identification with mathematics that can, in turn, translate into mathematics degree participation.

4 The English educational context

Our study is conducted in England, where all young people are required to take national examinations at age 16 (General Certificate in Secondary Education, GCSE), for which mathematics is compulsory. Attainment at GCSE shapes access to post-compulsory education and training, the most common of which is the academic route of A level (Advanced Level) qualifications. This typically involves students taking three subjects from age 16 to 18; although at the time of our data collection, some could opt to take AS level/s (equivalent to half an A level) alongside their main A level subjects. A levels are the key qualification route for entry to undergraduate degrees, which in the UK are usually specialised. Mathematics is an optional A level but is widely required or recommended for those wishing to continue in science, technology, and engineering. In England, Mathematics A level consistently has the most students taking it of all subjects (Johnson, 2020).

The paper focuses on three case study participants in the longitudinal qualitative study who chose to study mathematics at university, because they allow us to focus on how mathematics identities are sustained to the point where they make doing a mathematics degree possible. The cases of young people who took mathematics A level but who then chose not to pursue mathematics at degree level are discussed in a sister paper (Archer & Francis, under review). We use the concept of capital to map and identify the relative influence of particular factors at particular time points, within given contexts, so as to build a richer understanding of how mathematics identities, or habitus, develop over the long term in support of a mathematics degree trajectory.

5 Methods

The data for this article are drawn from the ASPIRES project, a 13-year longitudinal mixed methods study funded by the UK's Economic and Social Research Council (ESRC), which aims to understand young people's STEM trajectories from age 10 to 22. The study received ethical approval from UCL's ethics committee (REC1300) and follows the ethical code of the British Educational Research Association (BERA), ensuring free and informed consent (and offering the right to withdraw data) from all participants (with parents/guardians providing consent for children under the age of 18) and complying with UK data protection legislation for data treatment and storage.

The wider study includes surveys conducted with over 47,000 young people and longitudinal tracking of a sample of 50 young people (along with their parents) from age 10 to 22. In this paper, we focus on 17 semi-structured interviews that were conducted with three young men—Tom, Neb, and Gerrard—from the qualitative cohort. These three young people were chosen as the focus for this paper on the basis that they were the only three interview participants who went on to study for a degree involving mathematics, specifically a pure mathematics degree or, in Gerrard's case, a mathematics and computing integrated degree. We conducted interviews at six time points: the end of primary school (age 10), through compulsory secondary education (at ages 12/13, 13/14, 15/16), and at ages 17/18 and 20/21. As we only conducted interviews with Gerrard and Neb's mothers (Rayna and Ruth), we chose to exclude parental data from the present analysis, for reasons of parity. While 23 of the 50 students in the longitudinal interview sample took A level Mathematics, only Tom, Neb, and Gerrard went on to take mathematics degrees.

Parental interviews and recent young person interviews typically lasted around 1.5 h. Interviews were shorter when children were younger, for example, around 30 min at age 10. Interviews reported in this paper were conducted by ten members of the wider project, including the lead author. They were audio recorded and professionally transcribed. Interview schedules were informed by the literature and iteratively developed over the course of the study to capture the (changing) nature and range of influences on young people's educational and occupational aspirations and trajectories. They included key topics such as favourite and least favourite school subjects; views and experiences of school science (generally and by disciplinary area); STEM subject experiences; their aspirations, and the reasons for and influences on these; educational and occupational choices and the reasons for these; out-of-school interests; experiences of careers advice and guidance; and experiences of outreach and work experience. Parents were additionally asked about their parenting styles and practices (drawing on Lareau, 2003).

To strengthen the validity of the research, the researchers followed Guba and Lincoln's (1989, p. 237) suggestions for building credibility through "prolonged engagement" with research subjects (repeated interviews, conducted over 11 years) and through member checks (where previous insights and analyses were shared and checked with participants in subsequent interviews). To support dependability, the wider project provides descriptions of the research process in sufficient detail to enable another researcher to repeat the work. To support confirmability, all interviewers underwent training to provide a baseline standardisation of the ways in which questions were asked, prompted, and probed. During analysis, the development, iteration, and refinement of codes were recorded and developing analyses and interpretations were sense-checked and discussed between team members.

For each young person, the transcripts from their six interviews were combined and then summarised by a research team member into a chronologically organised extended case study that was then checked and iterated by the lead author to produce an agreed summary that was felt to accurately represent the young person's trajectory, their identification with mathematics, capital, and key influences on their trajectory. We retained any inconsistencies (e.g., within single interviews, in participants' accounts across time, and between their accounts and those of their parents) as we consider these both normal occurrences within biographies and relationships and revealing points of analysis, offering insights into tensions in how people narrate their selves. These summaries were read by team members to check interpretations.

Data were coded for examples of mathematics identity work, mathematics capital, and interplays between these. Specifically, potential examples of mathematics identity/identity work were identified and coded on the basis that they involved (i) the expression of mathematics-related dispositions (e.g., a "love" of mathematics, seeing mathematics as "useful" for jobs), (ii) recognition by others of one's mathematics competence (e.g., being seen by others as "naturally talented" at mathematics'; accorded a mathematics-related role on the basis of competence, such as a mathematics tutor or STEM ambassador), (iii) self-identification and investment in a mathematics identity (e.g., describing oneself as "good at maths"), and (iv) constructions of what it means to be a "maths person" (e.g., describing the attributes of someone who is seen as being good at mathematics, such as fast at mental calculations).

Potential examples of mathematics capital were identified and coded on the basis that they involved (i) mathematics-related forms of cultural capital with exchange value in the dominant educational field (e.g., strategic knowledge of mathematics education; investment of time and resource in supporting forms of mathematics attainment valued within school mathematics, such as independent, fast mental calculation); (ii) forms of mathematics capital with local exchange value (e.g., love of mathematics, practices of mathematics); (iii) mathematics-related social and cultural capital (e.g., family members with mathematics qualifications/jobs, watching mathematics-related TV together, doing mathematics together at home); mathematics-related family dispositions (e.g., family encouragement to continue with mathematics, family valuing of mathematics); and (iv) mathematics-related resources, activities, and practices (e.g., reading mathematics books, consuming mathematics-related media, extra-curricular mathematics opportunities; mathematics-related work experience). Following coding, the lead author worked iteratively, moving between the codes and data, to identify interplays of identity and capital within the young men's trajectories. These were then compared against each other and comparative interpretations of the cases were produced through discussion between the authors and through reference back with the wider literature.

6 Findings

We begin by considering two case studies of young men, Tom and Neb, who experienced smooth trajectories into mathematics degrees. These are then followed by a consideration of Gerrard's less smooth trajectory.

6.1 Tom

Tom lives with his parents and brother in a market town in South East England. He self-identifies as a middle-class young man of South Asian (Pakistani Muslim) heritage. When we met Tom at age 10, he was attending a local mixed state primary school. He saw himself, and was recognised by teachers, parents, and peers, as "naturally able" and "good at maths". Indeed, at the start of his first interview, Tom's opening words were "I'm 10 … favourite hobbies probably football, cricket and tennis and I'm gifted and talented for mathematics and science". During his first interview, and repeatedly in later years in subsequent interviews, he linked the emergence and cementation of his mathematics identity to a pivotal experience in primary school, when, aged 6 or 7, he won a competitive mathematics game that his year group had played against the year above. As he explained at age 10, Tom's victory was made all the more impressive when, in the final round, he beat a child who he described as the "cleverest boy in the year above". As Tom later reflected at age 21, "It was just seeing that … 'Okay, so this [mathematics] is actually something I can kind of excel at' – that was so much fun". Thereafter, Tom told us, he found mathematics "easy". At age 10, Tom also enjoyed doing mathematics at home, describing how "for fun" he would ask his dad to set him "really hard sums" to solve. He also talked about enjoying watching mathematics and science-related television with his father. Tom described his father and brother as being "interested" and "good at maths" and his uncle as "phenomenal" at mathematics.

At age 11, Tom moved to a comprehensive single-sex secondary school. His designation as gifted and talented at mathematics enabled him to access further mathematics enrichment and extension opportunities, e.g., "This year I've been to two maths workshops – one about matrices and one about problem solving, working out ratio, everything!", reinforcing Tom's sense of being "really at [the] top".

At age 12–13, Tom started to develop an interest in mathematics as a potential future career after his mother told him that she had heard through the media that there would be a strong future demand for mathematicians. At age 14–15, Tom briefly aspired to pursue a career in medicine, although as he recounted, his father advised him to maintain his interest in mathematics. Around this time, Tom was selected to attend a two-day mathematics workshop at an elite university, an experience that he both loved and that helped bolster his mathematics identity, as he met new friends and found a sense of community with peers "who love mathematics as much as I do". The experience motivated him to aspire to a mathematics degree so that he could meet more like-minded people. During this time, Tom also described doing work experience at his father's hospital, which he said gave him an appreciation and reassurance of how mathematics could be used in practical ways within disciplines such as medicine.

At age 15–16, Tom was given a role of providing mathematics tutoring for younger boys at his school, which he found interesting and enjoyable. At home, Tom continued to speak warmly of how he and his father enjoyed watching television words-and-numbers game show *Countdown* together—a practice that continued up until he left home for university.

At age 17–18, Tom was made deputy head boy at his school and was given responsibility for championing STEM within the school and inspiring younger students' interest in mathematics and science—a role that he thoroughly enjoyed. He considered applying to do a physics degree, but discovered that these courses tended to require interviews and written applications, which he described as being "one of the last nails in the coffin" for his consideration of physics at degree level. At age 18, he achieved A*, A*, and B in Mathematics, Further Mathematics, and Physics A levels. After A levels, Tom took a gap year to re-take Physics A level, during which he worked as a tutor and volunteer learning assistant at his school, providing mathematics and physics support.

At age 21, Tom was in his second year of an applied mathematics degree at an elite university, where he felt he was "becoming a mathematician", had "hit my stride", and was looking forward to seeing "where mathematics will take me". At age 21, Tom still enjoyed watching mathematics and science-related content, on YouTube, along with stand-up shows (for the "fun side" of the subjects). He read mathematics and science comedy books for pleasure, as well as what he described as "mid-level" mathematics and science books. And at age 21, he reflected on how his primary teachers had been a key part of building his mathematics identity and trajectory, as they helped him to "to see that I am good at mathematics". These "fantastic" teachers taught "beyond the test" and "pointed to more" mathematics-related interests that he could pursue outside school, motivating him to engage in independent learning. At age 21, Tom was contemplating three potential career routes in finance, research/academia, or engineering, all of which he felt he had relevant family connections to support.

6.2 Neb

Neb lives with his father and his mother, Ruth, in central London. He comes from an upper-middle-class family and self-identifies as a white British and Jewish young man. Neb attended a co-educational primary school in London. At age 10, Neb described how he found mathematics "easy" and felt he had a "natural affinity" with the subject. He explained how he always "looks forward" to mathematics at school and said "I just like doing things with numbers really". He explained that his family is generally "interested in mathematics and science" and recounted how his grandmother had been a mathematics teacher and his great uncle worked as a professor in a STEM discipline at an elite university. He said that during his spare time, he loved using science kits, playing with Lego, and going on family visits to science museums. He also voraciously read non-fiction science books and enjoyed learning about space: "I love science … I just like physics and science".

At age 11, he moved to an independent (fee-paying), single-sex secondary school. He maintained a love of the books and television programmes, enjoying particularly consuming the work of UK physicists such as Professor Stephen Hawking and Professor Brian Cox. He told us at this time that he enjoyed reading the "science bits" of newspapers and was inspired by visits to see his great uncle, the elite university professor. He attributed these visits to his aspiration to study mathematics or physics at an elite university ("that's probably when I first thought about it").

At age 13–14, Neb emphasised the importance of his "nice" teacher who had helped to grow his interest in mathematics and science. He felt that his interest in mathematics was still growing ("I think I've probably got more interested over time, okay, I remember in primary school, I used to always wait for maths, I always used to like maths lots and when I was much younger"). He engaged in a range of informal STEM learning activities, such as building his own computer at home for interest. He described himself at this time as "probably a little bit geeky" and pointed to how being a mathematics person is associated with being "clever". He also felt that many girls were not keen on mathematics because they "don't want to be seen as like a super academic, super clever person".

Age 15/16, he reflected "I guess it's just like how some people's minds prefer to work with like numbers and things" (age 15–16). At this age, Neb's mother, Ruth, organised a work experience placement for her son at a university physics department. The placement involved Neb making a robot, an experience he enjoyed and that helped to "make real" his aspirations to pursue a STEM trajectory. From age 16–18, Neb described finding his school careers guidance helpful for showing where mathematics could lead and reinforcing a mathematics degree as a viable and sensible option. He also attended university open day visits and careers evenings to find out more about options to study mathematics at the degree level. Neb met professors from elite universities at careers evenings and felt reassured by them that there was a high demand for STEM graduates. His school also helped him find out about the respective requirements for entry to mathematics versus physics degrees, which, Neb explained, helped him to make the strategic decision to apply for mathematics, which he discovered was a "more straightforward" process, requiring only a written application rather than an interview (as was common for a physics degree). He also noted that studying for a mathematics degree would still allow him to access any "interesting" physics modules, whereas the same would not be possible in terms of accessing mathematics module from a physics pathway. While he recognised that his father would have liked Neb to follow in his footsteps (into law), Neb explained his own choice of a mathematics trajectory as a useful and transferable option: "Ultimately, I think maths is probably the most useful subject to have …. because you can just apply mathematics to virtually anything […] I mean I think in virtually every job you use maths at some point". His great uncle also provided Neb with useful practical information and advice to help him apply for a mathematics degree.

At age 17–18, Neb described his enjoyment and pleasure in doing mathematics in his spare time, "I can just happily sit at my desk and do maths for a while". At age 18, he achieved A*, A*, and A in Mathematics, Further Mathematics, and Physics A levels and reflected "I think mathematics just comes to me more naturally". After A levels, Neb took a gap year to re-take the entry examinations for an elite university, during which time he worked as a private tutor in mathematics and science and volunteered as a learning assistant in the mathematics department of a state secondary school, something he described as "fun… and good for my own maths as well". He succeeded in his efforts and at age 21, Neb was studying for a mathematics degree at an elite university. He said that he remained interested in the subject but was now starting to gravitate towards the more physics-y side of mathematics ("I still lean quite strongly towards physics and sort of theoretical physics, the maths-y side of physics […] It's just what I've always really gravitated to").

6.3 Discussion of Tom and Neb: the ongoing mutual reinforcement of identity and capital producing smooth, successful mathematics degree trajectories

We interpret both Tom's and Neb's mathematics trajectories as supported and facilitated through a virtuous circle of mutually reinforcing interplays between identity and capital. For instance, both young men came from families where close adult relatives already identified with mathematics and possessed considerable mathematics capital, as epitomised by Tom's father, uncle, and brother and Neb's great uncle. Within their families, both described a range of everyday family practices that further supported the development and nurturing of mathematics competence (e.g., Tom's father setting him "really hard sums" for fun) and positive dispositions towards mathematics (e.g., Neb's family providing mathematics-related kits, visits, books, and so on; Tom and his father watching the popular UK TV show *Countdown* together). Importantly, the forms of mathematics identity work and capital supported by their families (for instance, supporting Tom and Neb to practice, value, and become proficient at fast mental mathematics) closely aligned with school mathematics and hence operated as exchange-value capital, supporting the boys' academic attainment.

The young men's performances of competence within school mathematics were accorded symbolic and social recognition in the form of top grades in mathematics tests and examinations and Tom's official designation as "gifted and talented", and are also exemplified by Tom's "winning" of the classroom mathematics contest. This symbolic capital of recognition then in turn opened up access to further forms of exchange value capital (e.g., extra-curricular mathematics resources, workshops, masterclasses) that could further support high attainment and mathematics identity work, notably self-recognition (as good/exceptional at mathematics) and capital relating to the intrinsic enjoyment of finding mathematics pleasurable and "easy". Indeed, we noted how both Tom and Neb spoke about how their interest in mathematics was intertwined with an identification as being "good at maths" that was grounded in notions of "ease" and a "natural" talent for the subject. These forms of capital also enabled the young men to strategically navigate their post-16 choices, for instance maximising their chances of being accepted on to a degree at an elite university and, in Neb's case, providing a "rational" argument to his father for pursuing mathematics rather than law. These interplays of identity and capital then continued through further self-reinforcing cycles, opening up further access to capital and identity work, such as through being offered mathematics-related tuition and leadership roles. In this way, the repeated interplay over time of mathematics capital and identity work, across home, school, and out-of-school settings, produced what we might call a wrap-around of support that helped produce, sustain, and grow the young men's interest, investment, and attainment in mathematics, producing smooth trajectories into mathematics degree study.

6.4 Gerrard

Gerrard lives in London with his sister, father, and mother, Rayna. His family are working-class and arrived in the UK from Eastern Europe when Gerrard was aged six and settled in London. Gerrard's parents have limited formal mathematics capital and do not identify as competent at mathematics. For instance, Gerrard's mother, Rayna described herself as "bad at maths", although Gerrard's father said he was "interested" in STEM areas and Gerrard described how, over the years, the two enjoyed watching science-related television together. Gerrard attended a co-educational primary school and explained how, prior to arriving in the UK, his academic performance in his Eastern European country of origin had been strong across the board, saying that he was "good at like most stuff, but nothing that I would be, like, exceptional in". At age 10, Gerrard told us that he enjoys mathematics "because I am good at it", which he contrasted with not feeling as good at other subjects, which he had found more difficult following the transition due to their greater reliance on the English language.

At 11, he moved to a mixed state comprehensive secondary school. At age 13, he told us "I *really* like mathematics". Around age 14, he was selected for an extra-curricular mathematics masterclass at an elite London university. He explained that his passion for mathematics continued to grow, although he did not enjoy the "atmosphere" of the university where the masterclasses were held and decided that he would not apply there in the future. Around this time, he also undertook some work experience in the engineering department of a train company, that his mother helped him access. However, he described the experience as "bad" and demotivating. Despite his stated ongoing "passion" for mathematics, Gerrard's school did not provide him with any information about the possibility of mathematics-related careers and he started to consider computing as a possible future option when a family friend told him that computing jobs "paid well" and there would be a strong demand for jobs in this area in the future.

At age 16, Gerrard moved to a mixed sixth form college, taking A levels in Mathematics, Further Mathematics, and Physics. During his final A level year, Gerrard missed two months of college due to health issues and had to work very hard to catch up on missed learning. At age 18, he achieved A*, A*, and A in Mathematics, Further Mathematics, and Physics A levels. Gerrard's overwhelming concern for his future was "to be successful financially … so that I support my parents and just give back to them". Despite his stated passion for mathematics and physics, Gerrard applied for an integrated mathematics and computing degree, a decision that he explained as a "compromise […] because if I only studied what I want to enjoy … I think that's a bit selfish".

Rather, he said he wanted to be able to financially provide for his family, so chose a degree that he thought offered a way to do this ("So yeah I just want to give back").

After A levels, Gerrard took a gap year—originally planning to take up a study scholarship in China, although due to a mix-up, he missed a deadline, and instead spent the year taking a Chinese language course. He came to regret taking the year off:

> It's not a good choice, it just gets you out of the working mindset. You forget a lot of things, you feel sloppy afterwards. … It's a lot harder to get like motivation I think, especially if you don't do anything you know related to education during that time.

At age 21, Gerrard was in his second year studying for a four-year integrated master's degree in mathematics and computer science at an elite university. He had had to re-take his first year after failing the computer science element and was worried for his future: "I'm not really enjoying my degree too much, I'm not really doing too amazing in it". In this interview, he also reflected back on the challenges that he had faced in his life, such as when he arrived in the UK, not being able to speak English, and mathematics was the only subject in which he could demonstrate his abilities. He reflected back in his final interview, aged 21:

> None of that stuff that [I] was good [at before] I was good at any more, because I can't speak the language so I wasn't good at writing, this and that. But the only thing that I was still good at was mathematics, because it's the same right, it's just numbers. … So it was the only thing that I sort of felt like some pride in because for everything else I was, you know, considered so stupid you know? Put in the bottom classes. […] So I think that pushed me to like carry on with that.

He regretted that his school did not offer any enrichment: "my secondary school didn't have any like physics-related clubs that you could do after school". As he further explained, "they could have like put more effort into extending people's learning past just, you know, in class". Similarly, he recalled: "My college was really big on just getting kids the grades you know. It wasn't really much on you know building a love and interest for the course".

At age 21, Gerrard regretted not having taken a mathematics degree ("I think I would have preferred to have studied something that I deeply enjoyed"), and recognised how much harder his journey had been compared to his peers from more affluent backgrounds ("I just feel like students from poorer backgrounds, they need to sacrifice everything to … like get into the uni").

> I do have some regrets actually. … If I could go back maybe I would just pick pure mathematics. … I would have liked those, but my parents […] they wanted to consider something that you know had more of like a job opportunity like engineering or computer science.

7 Discussion of Gerrard: how misalignment and an absence of exchange-value capital can hinder a mathematics degree trajectory

We identify several ways in which Gerrard's trajectory was supported by instances of alignment between and access to symbolic and cultural capital (along with capital with a more local exchange value) that facilitate his mathematics identity work, recognition, and attainment. For instance, Gerrard's mathematics identity and competence is supported at an early age by the alignment between his mathematics educational experiences in his country of origin and the system he encountered in the UK on arrival. The dispositions nurtured within his family—towards hard work and providing for his family—can also be interpreted as supporting his investment in the UK education system. His self-identification and recognition as "good at maths" is further amplified by the misalignment between his linguistic capital and his classroom experience on arrival, when mathematics was the only subject he could attain well in and "that I sort of felt like some pride in because for everything else I was, you know, considered so stupid". Gerard's ability to perform well at school mathematics provided him with symbolic recognition, which opened up access to a university masterclass, but he did not enjoy the "atmosphere" of this and reported considerably fewer enrichment and recognition opportunities compared with Tom and Neb.

In contrast, we interpret Gerrard's potential mathematics trajectory to be hindered and curtailed by instances of misalignment between his capital and school mathematics, such as the absence of cultural capital pertaining to the exchange value of a mathematics degree within the labour market, which leads him to choose a degree for which he is comparatively less prepared. In comparison with Tom and Neb's trajectories, Gerrard has much less access to different forms of mathematics capital that can be generated within and be exchanged across different fields (e.g., the family, education), such as developed through mathematics enrichment opportunities, mathematics-related HE and/or careers support, work experience, and mathematics-related activities during his gap year. The absence of these opportunities and forms of capital gave him relatively limited opportunities for mathematics identity recognition and the practice of mathematics. We interpret this as largely reflecting inequalities in the distribution of symbolic capital by social class.

In this way, we interpret the differences between Tom/Neb's mathematics trajectories and Gerrard's trajectory as exemplifying how classed inequalities work to sustain and promote "smoother" mathematics degree trajectories among middle-class students through mutually reinforcing interplays of identity and capital while curtailing/hindering a mathematics degree trajectory among working-class students due to the unequal distribution of capital, greater misalignment between student capital and field, and through the restriction of opportunities for the mutually reinforcing interplay of identity and capital across time and field.

8 Discussion across all three cases: obscuring the mechanisms supporting the social reproduction of inequalities in mathematics degree participation

All three of the young men talked about their enjoyment and love of "doing" mathematics, which they also related to the pleasure of it being something that they saw themselves (and are recognised by others) as being "good at". In this respect, their accounts might be interpreted as illustrating the interplay between mathematics identity work and capital, reinforcing findings from previous studies (e.g., Black & Hernandez-Martinez, 2016). As discussed above, we interpret the young men's attainment in mathematics as produced and sustained through interplays of various forms of social, cultural, economic, and symbolic capital and identity work across home and school mathematics settings. However, the data also hint at potential classed differences in how the young men understood their mathematics competence, which, we extrapolate, may also contribute to the social reproduction of classed inequalities in mathematics participation.

For instance, particularly in his interview at age 21, Gerrard identifies a range of social and economic inequalities shaping his trajectory, including the way in which his experience on arrival in the UK and his different linguistic capital meant that his mathematics competence became more prominent (and a source of investment and motivation) due to the negation of his (equal) competence in other subject areas. He feels that he had less support and opportunities from his school to facilitate a mathematics degree trajectory and felt that generally students from working-class backgrounds have fewer opportunities and less support than their middle-class peers and thus have to work much harder to access and do well at university. Differences between Gerrard's upbringing and identity and school mathematics education also seem to shape his trajectory. Over the years, Gerrard makes extensive reference to his "passion" for mathematics, which he feels he has to subjugate to his desire to make an instrumental, "strategic" choice of a more applied degree that will better enable him to fulfil his commitment to securing a job that will enable him to financially provide for and thus "give back" to his family, rather than taking a degree on the basis of a more individualised notion of self-fulfilment. That is, taking a more "abstract" degree, such as a pure mathematics degree, is experienced as a riskier and more conflicted choice by Gerrard compared with Neb and Tom, due to differences in their classed locations.

Moreover, whereas Gerrard conveys some recognition of the role of social and contextual factors in producing his mathematics competence and the ways in which his university trajectory has been negatively impacted by wider inequalities in capital, both Tom and Neb talked extensively about being "naturally" able at mathematics, such as through references to being "exceptional" at the subject (Tom) and having a "knack for numbers" (Neb). As has been found in other studies (e.g., Bartholomew et al., 2011; Mendick, 2006), Tom and Neb linked their enjoyment of mathematics to their competence and "ease" in the subject. Such constructions echo existing research that understands dominant forms of mathematics identity work as organised around notions of intellectual superiority and "natural giftedness" (Mendick, 2005, 2006). We interpret such constructions as practices of distinction (Bourdieu, 1984), in which "natural superiority" in mathematics is signalled through "ease" of attainment and through embodied constructs such as the "maths brain": "Social subjects, classified by their classifications, distinguish themselves by the distinctions they make, between the beautiful and the ugly, the distinguished and the vulgar, in which their position in the objective classifications is expressed or betrayed" (Bourdieu, 1984, p. 6).

In addition, we note that Tom and Neb's accounts align closely with the reasons given by the survey sample of mathematics degree students reported by Archer et al., (2023a, 2023b, 2023c, 2023d, 2023e, 2023f), in which the most common reason given for choosing a mathematics degree was feeling "good at" the subject. As Archer et al. discuss, this reason was predominantly given by socially privileged students (namely male and from the least socially deprived quintile) whereas less privileged mathematics students tended to explain their choice mainly as due to subject interest/passion (echoing Gerrard's account).

Drawing on Bourdieusian theory, we suggest that dominant associations of mathematics liking and competence with "natural talent/giftedness" can be understood as operating through misrecognition and symbolic violence, whereby privileged students may be more likely to attribute their mathematics "passion" and attainment to "natural talent" and aptitude (rather than their possession and deployment of exchange-value capital and the benefits deriving from the alignment between their own identity, capital and the field in question), thus obscuring the ways in which social inequalities produce and sustain differential patterns of participation and justifying/naturalising the ongoing dominance and over-representation of privileged students taking mathematics degrees.

9 Conclusion

In this paper, we analysed longitudinal qualitative data from three case study young men who had been interviewed over an eleven-year period, from age 10/11 to 21/22, and who went on to study for undergraduate degrees in mathematics. We identified how the interplays between identity and capital that have previously been found to shape school students' engagement and aspirations in mathematics are also evident among students' degree level trajectories. The analysis considered how the mutually reinforcing interplay between mathematics capital and identity work plays out longitudinally, over time, and across home, school, and out-of-school settings to shape the young men's mathematics trajectories over time, noting how inequalities in the distribution of capital played a part in the social reproduction in inequalities in mathematics degree participation, such that the two more socially privileged learners (Tom and Neb) experienced "smoother" mathematics degree trajectories than Gerrard.

Our findings reinforce existing literature that emphasises the importance of recognition, and particularly symbolic recognition, for mathematics identity (Mendick, 2006; Walker, 2011), suggesting that this can be important not only for growing and sustaining personal investment in identity work in relation to mathematics (e.g., seeing oneself as "good at maths") but also for opening up access to further forms of capital (such as mathematics-related extra-curricular opportunities, roles, and experiences) that in turn support mathematics attainment, competence, identity work, and recognition, which can form self-reinforcing "virtuous" loops. From their early experiences through to their later entry to elite mathematics degrees, the young men's constructions of mathematics identity emerged from and were sustained through deployments of various forms of mathematics capital which in turn fed into them seeing themselves and being recognised by others, as "naturally" and exceptionally good at mathematics. Yet, when in Gerrard's case symbolic recognition did not open up extensive further forms of capital, it restricted the potential for a mathematics degree trajectory.

Of course, from a Bourdieusian perspective, the role of mathematics capital in supporting or mediating mathematics identity work may not be new or unexpected. However, we suggest that the application of a Bourdieusian lens to longitudinal data has helped elucidate how mathematics degree trajectories are developed, negotiated, and sustained (or restricted) over many years, not only "in the moment" (as per most prior classroom research, e.g., Gholson & Martin, 2017, 2019), echoing findings from wider work on the role of social capital and community resources in supporting mathematics identity among Black students in the USA (Walker, 2006, 2012). Our findings also suggest that similar interactions of identity and capital are required to support mathematics trajectories as has been found by wider research conducted in relation to other disciplinary areas, such as computing (Holmegaard et al., 2024). Moreover, our findings suggest that not only is considerable identity work required to make possible identification as being "good at maths" (e.g., Ibourk et al., 2022)—access to and mobilisation of capital over time is also required.

While it is not possible to generalise from three cases, we suggest that our analyses of the young men's trajectories provide some useful food for thought for further exploration. For instance, further consideration might be usefully given to exploring with wider samples whether identifying as "good at maths" and pursuing a mathematics degree trajectory require a similar interplay of exchange-value capital and identity work. Future research might also consider the importance of primary school as a potentially formative space for the "emergence" of mathematics identity and further attention might usefully be given to understanding how identity work, recognition, and capital become entwined in mutually reinforcing "loops" that extend over time and field, to produce successful mathematics degree trajectories—investigating the implications of these interactions for the ongoing social reproduction of inequalities in mathematics degree participation.

Data availability The data sets analysed for the present study are not currently publicly available in order to protect participant anonymity due to the extensive, potentially identifying, level of detail contained across multiple longitudinal interviews from each participant. Anonymised data summaries will be available from the authors on reasonable request after the end of the funded research period.

Declarations

Conflict of interest The authors declare no competing interests.

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