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A Bourdieusian Analysis of the Conversion Between Mathematical Achievement and Science Capital

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Abstract: Mathematics serves as a universal language and set of thinking tools for science. While prior research indicates associations between academic success in mathematics and science, there is a gap in the research that explores the possible relationship between mathematical achievement during early secondary school (ages 11-13) and subsequent participation in advanced science courses during senior secondary school (beyond age 16). This research is valuable because it could provide further insights into how early achievement in non-science subjects is related to senior participation in science. The analysis of national mathematics test data found that students who studied different science subjects in senior secondary school all had stronger foundational mathematical skills than those who did not. The results differed according to science subjects. The analysis indicated differences of over 7.2 months of equivalent learning at early secondary level in favour of those who studied physics, 6.1 months for those who studied chemistry and 2.5 months for biology. I apply a Bourdieusian lens as a way of explaining students' conversion of mathematical achievement into participation as a form of science capital. These findings add empirical weight to previous research promoting mathematics as a crucial foundation for science learning. This research has implications for policies and practices that promote learning in mathematics and science pathways.

***Keywords*:** longitudinal, National Assessment Programme-Literacy and Numeracy (NAPLAN), Australia

1. Introduction

The diminishing proportions of students opting for subjects related to science, technology, engineering, and mathematics (STEM) in senior education has become a matter of concern in numerous post-industrial countries (Archer et al., 2013; Commonwealth of Australia, 2017; Okrent & Burke, 2021). Students who do not study senior secondary STEM subjects leave the so-called 'STEM pipeline', which ultimately impacts the numbers of those who continue a STEM pathway into tertiary studies and beyond (Hobbs et al., 2017). An economic imperative fuels some stakeholder calls for reform in preparation for expected shortages in STEM labour markets (Carter, 2017). Given the 'leaky pipeline' and concerns about labour shortages, it is important to examine trends and reasons why some students stay or leave science. Globally, researchers have identified different factors that are likely to impact high school science participation. These factors include the quality of teaching, student's enjoyment; the perceived relevance of the subject, student's perceptions of their own competence, and access to cultural, social and economic-related resources (Bennett

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et al., 2013; Dillon, 2009). Declining participation rates are exacerbated by the decreasing representation of certain student groups (UNESCO, 2017). In the United States for instance, minority groups such as African Americans and Latinos (Okrent & Burke, 2021). In the United Kingdom, students from low Socio-Economic Status backgrounds (SES) are underrepresented at the General Certificate of Secondary Education (GCSE) level (The Royal Society, 2008; Higgins, 2018). Australian research has identified SES and First Nations status as negative predictors of senior science participation (Cooper et al., 2018; Cooper & Berry, 2020). Moreover, the underrepresentation of females in some STEM fields, including physics and advanced mathematics, has been documented in different post-industrial countries (Higgins, 2018; UNESCO, 2017). To tackle these challenges, several interventions have been suggested. These interventions encompass initiatives such as additional supports for underrepresented student cohorts, revamping science curricula, implementing mentorship programs, establishing partnerships with relevant industries, and enhancing awareness of career prospects in the field of science (Hobbs et al., 2017). While recognising that the influence of various factors is likely to impact student trajectories, this discussion specifically focuses on the potential relationship between mathematical achievement and participation in science. In the following sections, I will explore the relationship between maths and science as the foundation for this study.

Mathematics is a vital part of science. It serves as the fundamental language and toolkit essential for a deeper understanding and analysis of scientific concepts (Basista & Mathews, 2002). Science teachers often rely on mathematical concepts and skills to teach their subjects (Frykholm & Meyer, 2002). Certain disciplines like physics demand a substantial level of mathematical knowledge and its practical application while on the other hand, disciplines such as chemistry, biosciences, and psychology typically necessitate an intermediate level of mathematical proficiency, as highlighted by Tariq (2002).While there is an existing evidence base that examines synergies between science and maths, there are few empirical studies that examine relationships between outcomes in mathematics and science. An exception to the former is research by Wang (2005), who described moderate correlations between science and mathematics achievement in his analysis of over 50 countries. Research conducted by Kurumeh et al. (2013) revealed a substantial and statistically significant positive correlation between mathematics achievement and science achievement. Although there is evidence suggesting a link between maths and science achievement, there is a lack of longitudinal research that investigates the potential connection between mathematical achievement in early secondary school and later participation in senior secondary science. To ensure clarity, I employ the term 'early secondary' to denote students in the age range of 11-13 years, while 'senior secondary' or 'post-16' refers to students who are 16 years of age or older. This research is valuable because it could provide further insights into how achievement in non-science subjects is related to participation in science. It may also add empirical weight to previous research promoting mathematics as a crucial foundation for science learning.

To achieve our research objective, I utilised data linkage techniques to collect two distinct datasets from individual students. These datasets comprised the following information: (1) the students' mathematics achievement during early secondary school, and (2) their participation in physics, chemistry, and biology courses during senior secondary school. I will elaborate on this process in the subsequent discussion, but before that, I will provide a comprehensive overview of the achievement testing dataset employed in this study.

2. Achievement testing data

Education stakeholders are increasingly embracing the use of big data such as testing achievement, to inform policy, school directions and pedagogical decisions. In Australia, a national measure of students' language and mathematical achievement is collected from a test called the National Assessment Programme-Literacy and Numeracy (NAPLAN). NAPLAN results are used to compare the performance of different schools and education systems, and to identify trends and patterns in student learning across the country. In Australia, the NAPLAN assessments are mandatory for students at certain educational milestones, specifically in Years 3 (ages 8-9 years), 5 (ages 10-11 years), 7 (ages 11-13 years), and 9 (ages 14-15 years). Within the context of this research, participants' year 7 achievement data is examined. The NAPLAN test aims to evaluate students' comprehension in various areas, including number sense, geometry, algebra, functions, patterns, measurement, probability, statistics, and mathematical problem-solving skills. (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2016).

3. Aim and research questions

The objective is to examine associations between students' mathematical performance during their initial years of secondary school (ages 11-13) and subsequent participation in science subjects at the senior secondary level (16 years and older). Our research centered on the following aspects:

1. Are there associations between students' early secondary NAPLAN mathematics scores and their senior secondary science participation?

2. What explanatory mechanism can be used to describe the process by which mathematical achievement can be transformed into science capital?

4. Method

As discussed, data linkage was used in this research to combine two separate datasets to answer the research questions. This process involves combining multiple sources of information that relate to the same individual (Dong & Srivastava, 2015). The researchers in this study used a unique student identifier (USI) to match the mathematical achievement test results from NAPLAN with students' reported science participation in the Longitudinal Surveys of Australian Youth (LSAY). Of the total sample size in Wave 1 of the LSAY (n = 14,530), approximately one third (n = 4,567) were 16 years old or above and hence met the eligibility criteria for this study. Consent was sought in Wave 2 of the LSAY to link NAPLAN data. Attrition between Waves 1 and 2 of the LSAY meant the researchers were able to link 1,235 (27%) of eligible participants with both their senior secondary science participation (physics, chemistry, biology) and early secondary NAPLAN results (mathematics achievement testing). Linked datasets often consist of complex data structures where data from multiple sources are combined. This complexity can obscure the underlying mechanisms of missingness, making it difficult to accurately assess whether data is missing at random. I will return to this point later in the paper. The analysis in this study compares the mean scores in mathematical achievement among students who did and did not participate in physics, chemistry, and biology (binary dependent variable-participation/no participation). To accommodate the nonlinear trajectories of students' NAPLAN scores, I employed the equivalent year levels (EYL) methodology, as suggested by Goss and Sonnemann (2016). This approach allows for a more nuanced understanding of students' academic advancements by accommodating the nonlinear trajectories of their performance scores, thereby providing a more accurate representation of their learning progress over time. These EYL values were developed to estimate a typical student's growth trajectory and map NAPLAN scale scores onto that trajectory across different year levels. Instead of using arbitrary NAPLAN scale scores, calculating the EYL scores for student groups means it is possible to see how far ahead or behind other groups are in terms of equivalent learning. Further details about the EYL measure can be found in Goss and Sonnemann (2016). Chat GPT was used to facilitate the production of this article at different stages of the article to help with phrasing, flow, and word choice.

4.1 *Science capital as an analytical lens*

For this study, I adopt a science capital lens as the theoretical framework. Science capital is conceptualized as a framework that consolidates different forms of economic, social, and cultural capital, specifically relevant to attainment, engagement and/or participation in science (Archer et al., 2013). For instance, science capital may encompasses science-related qualifications, knowledge, interests, social networks, and engagement in scientific activities. The concept of science capital is built on the work of Bourdieu (1977), who argued that families convert their access to economic capital into valued forms of cultural and social capital, which impacts participation and outcomes in education. Theories of science capital foreground inequity by examining student cohorts who are more and less likely to have access to science capital. We know from previous research, for instance, that SES is a significant predictor of senior secondary science participation (Cooper et al., 2018; Cooper & Berry, 2020). While many studies tend to focus on demographic factors when examining science capital (e.g., SES, gender, ancestry), the kind of science capital we are interested in this research is a participation-based form. To recap, the intention is to adopt a Bourdieusian lens to examine the relationship between mathematical achievement and its conversion into a form of participatory-based science capital.

5. Results

Research question 1: Are there associations between students' early secondary NAPLAN mathematics scores and their senior secondary science participation?

Physics: As shown in Figure 1, the mean average maths achievement score for those who participated in physics was an EYL of 7.32 (test score = 562.15, SD = 109.37), compared to an average EYL of 6.72 (test score = 547.53, SD = 122.16) for who did not participate. This represents an average difference between groups of approximately 15 points, equating to an EYL difference of 7.2 months of equivalent learning in favour of those who studied physics.

Chemistry: Shown in Figure 1, the mean average maths achievement score for those who participated in chemistry was an EYL of 7.23 (test score = 560.42, SD = 120.85), compared to an average EYL of 6.72 (test score = 547.67, SD = 109.46) for who did not participate. This represents an average difference between groups of approximately 13 points, equating to an EYL difference of 6.1 months of equivalent learning in favour of those who studied chemistry.

Biology: As shown in Figure 1, the mean average maths achievement score for those who participated in physics was an EYL of 7.10 (test score = 557.11, SD = 116.11), compared to an average EYL of 6.89 (test score = 551.64, SD = 115.74) for who did not participate. This represents an average difference between groups of approximately 6 points, equating to an EYL difference of 2.5 months of equivalent learning in favour of those who studied biology.

To summarize, the results show associations between students' early secondary mathematics achievement and senior secondary science participation. The extent of these associations, as shown by the EYL differences, vary across different science subjects. Below, I explore the implications of these results in more detail.

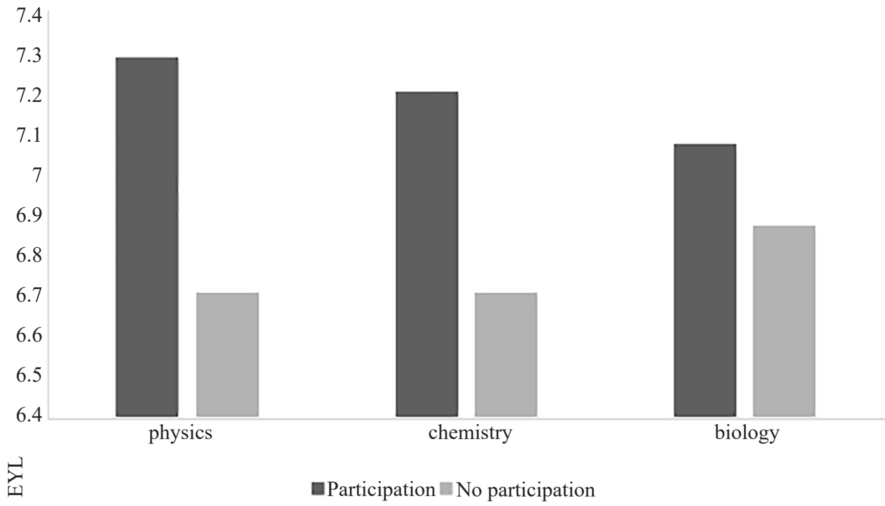

Figure 1. EYL differences in maths achievement according to science participation

6. Discussion

This research found that students who participated in science courses had, on average, higher early secondary mathematical achievement scores in physics, chemistry, and biology. The size of the differences varied by science subject. The largest difference was seen in physics, where students had early secondary mathematical abilities that were, on average, more than 7 months ahead of those who did not study it. Consistent with earlier observations in this field, physics and engineering courses require a high level of mathematical knowledge and application (Tariq, 2002), and students may struggle with the advanced maths skills required in these subjects (Chen et al., 2021). In chemistry, the average early secondary mathematical ability of students was, on average, more than 6 months ahead of those who did not study it. Chemistry has been described as its own language, with its own symbols, vocabulary, and syntax (Childs et al., 2015). As discussed, Tariq (2002) classified chemistry as a subject requiring an intermediate level of mathematics. The difference in mathematical ability was smallest in biology, where students had early secondary mathematical abilities that were, on average, 2.5 months ahead of those who did not study it. This research represents a novel contribution to the field by quantitatively measuring the differences in early secondary mathematical achievement between students who stay or leave science in senior secondary school, something that has not been done in previous research. This study supports previous findings on the important links between mathematical skills and outcomes in science. It confirms early mathematical achievement is associated with students' future science participation, especially in physics and chemistry. By implication, improving mathematical skills, particularly in formative years, may be an effective way to increase student retention in senior secondary science. It is important to note, however, that mathematical understanding is just one factor that appears to affect retention and that addressing issues of disadvantage and exclusion for underrepresented student groups is also crucial. To effectively teach science, it is important for educators to understand the literacy and numeracy skills required and to take responsibility for teaching these skills to their students. Collaborating with colleagues is likely to help distribute the responsibility of supporting students' mathematical development across the teaching team. Some science educators may also benefit from professional learning opportunities that help them effectively incorporate mathematical competencies into their teaching pedagogy.

Research question 2: What explanatory mechanism can be used to describe the process by which mathematical achievement can be transformed into science capital?

Mathematics is an act of culture, deeply embedded in people's daily lives. It serves as a language, a source of power, and an ideology, shaping how individuals see the world (Bills & Hunter, 2015). A Bourdieusian lens sees mathematical achievement as a form of cultural capital. Our analysis has shown that students leverage their mathematical achievement, conceptualised here as cultural capital, in the early years of secondary school and convert it into forms of science capital-in the context of our research, during the later years of secondary school. Consequently, for students who have the opportunity to participate in senior secondary science, there is a cumulative effect that boosts students' access to science capital further. Within the science classroom, dominant forms of capital are actively transmitted. Students who possess adequate capital of the relevant dominant type are in a favourable position to enhance their access to valued capital even more. (Claussen & Osborne, 2013; Du & Wong, 2019). Students who have access to resources, often through their caregivers, can convert these resources into different forms of valued capital. Those with plentiful access to capital, which aligns with the values and discourse of the science classroom, are more likely to be successful in science. If students do not possess the required capital, they are likely to face more barriers to participation. As a result, inequity concerns persist within our science classrooms, where students are either insiders or outsiders based on the extent of valued capital they have accumulated. Future research in this space may draw on students' demographics such as SES, gender, ancestry etc. to further explore possible associations between maths-related cultural and science capitals. Further research is necessary to fully understand the relationship between mathematical achievement, cultural capital, and the conversion into science capital. Until then, it is not possible to draw definite conclusions.

7. Conclusion

The research findings indicate that students who engaged in science subjects during senior secondary school demonstrated stronger foundational mathematical skills relative to those who did not participate. The results differed according to science subjects. Through the analysis, it is argued that students use their mathematical skills from the early years of secondary school to develop science capital during the later years of secondary school. This study innovates upon previous research in two significant ways. First, there is sparse empirical research examining the connection between students' early mathematics achievement and their participation in senior secondary science. Second, the use of data linkage can provide valuable insights without the need for additional data collection and minimises the burden on participants. Currently, the use of data linkage in science education is almost non-existent and there are significant opportunities in this space. Researchers in fields outside of science education have recognised the benefits of data linkage, including the potential to gain more complex insights and avoid costs associated with data collection. This research has limitations that need to be acknowledged. One main limitation is the relatively low percentage of cases that were able to be linked across datasets, which limits the ability to generalise the findings and highlights the exploratory nature of the research. Furthermore, this research does not provide further insights into the reasons for noted associations between achievement in mathematical achievement and science participation. While I have discussed possible explanations for these associations based on the research literature, further research is needed to better understand the underlying causes.

Conflict of interest

The author declares no competing financial interest.

References

Archer, L., Osborne, J., DeWitt, J., Dillon, J., Wong, B., & Willis, B. (2013). Young people's science and career aspirations. London, England: King's College London.

Australian Curriculum, Assessment and Reporting Authority. (2016). NAPLAN 2012-2016 test papers. https://www.acara.edu.au/assessment/naplan/naplan-2012-2016-test-papers

Basista, B., & Mathews, S. (2002). Integrated science and mathematics professional development programs. *School Science and Mathematics, 102*(7), 359-370.

Bennett, J., Lubben, F., & Hampden-Thompson, G. (2013). Schools that make a difference to post-compulsory uptake of physical science subjects: Some comparative case studies in england. *International Journal of Science Education, 35*(4), 663-689.

Bill, T., & Hunter, R. (2015). *The role of cultural capital in creating equity for pasifika learners in mathematics*. Mathematics Education in the Margins.

Bourdieu, P. (1977). *Power and Ideology in Education*. Oxford University Press.

Carter, L. (2017). *Neoliberalism and STEM education: Some Australian policy discourse*. Canadian.

Chen, J., Pereira, J., Li, X., Zhou, Y., Tamur, M., & Syaharuddin, S. (2021). Correlation between mathematics and physics achievement of senior high school students. *Tarbawi: Jurnal Ilmu Pendidikan, 17*(1), 14-26.

Childs, P. E., Markic, S., & Ryan, M. C. (2015). The role of language in the teaching and learning of chemistry. *Chemistry Education: Best Practices, Opportunities and Trends*. https://doi.org/10.1002/9783527679300.ch17

Childs, J., Markic, E., & Ryan, M. C. (2015). The role of language in the teaching and learning of chemistry. In John Wiley & Sons(Eds.), *Chemistry Education: Best Practices, Opportunities and Trends*. https://doi.org/10.1002/9783527679300.ch17

Claussen, S., & Osborne, J. (2013). Bourdieu's notion of cultural capital and its implications for the science curriculum. *Science Education, 97*(1), 58-79.

Commonwealth of Australia. (2017). Science and maths in Australian secondary schools datasheet. https://www.chiefscientist.gov.au/2016/07/science-and-maths-in-autralian-secondary-schools-datasheet.

Cooper, G., Berry, A., & Baglin, J. (2018). Demographic predictors of students' science participation over the age of 16: An Australian case study. *Research in Science Education, 50*(1), 361-373.

Cooper, G., & Berry, A. (2020). Demographic predictors of senior secondary participation in biology, physics, chemistry and earth/space sciences: Students' access to cultural, social and science capital. *International Journal of Science Education, 42*(1), 151-166.

Dillon, J. (2009). On Scientific Literacy and Curriculum Reform. *International Journal of Environmental & Science Education, 4*(3), 201-213.

Dong, X. L., & Srivastava, D. (2015). *Big data integration*. Morgan & Claypool Publishers.

Du, X., & Wong, B. (2019). Science career aspiration and science capital in China and UK: A comparative study using PISA data. *International Journal of Science Education, 41*(15), 2136-2155.

Frykholm, J. A., & Meyer, M. (2002). Integrated instruction: Is it science? Is it mathematics? *Mathematics Teaching in the Middle School, 7*(9), 502-508.

Goss, P., & Sonnemann, J. (2016). *Widening Gaps: What NAPLAN Tells us About Student Progress*. APO.

Goss, P., Emslie, O., & Sonnemann, J. (2018). *Measuring student progress: A state-by-state report card-technical report*. Grattan Institute.

Higgins, J. (2018). Why not physics? A snapshot of girls' uptake at A-level. https://www.iop.org/sites/default/

files/2018-10/why-not-physics.pdf
Hobbs, L., Jakab, C., Millar, V., Prain, V., Redman, C., Speldewinde, C., Tytler, R., & van Driel, J. (2018). Optimising STEM industry-school partnerships: Inspiring Australia's next generation. https://www.chiefscientist.gov.au/sites/default/files/2019-11/optimising_stem_industry-school_partnerships_-_final_report.pdf
Kurumeh, M., & Mohammed, A. (2013). Achievement in mathematics as a correlate of achievement in sciences in secondary schools in Makurdi local government area of Benue State, Nigeria. *Journal of Emerging Trends in Educational Research and Policy Studies, 4*(2). https://hdl.handle.net/10520/EJC137559
Lyons, T. (2006). The puzzle of falling enrolments in physics and chemistry courses: Putting some pieces together. *Research in Science Education, 36*(3), 285-311.
Okrent, A., & Burke, A. (2021). *The STEM labor force of today: Scientists, engineers, and skilled technical workers NSF*. NSF-National Science Foundation. Mahwah, NJ: Lawrence Erlbaum Associates.
The Invergowrie Foundation STEM. (2017). Girls' future: Our future. *Journal of Science, Mathematics and Technology Education, 17*(4), 247-257.
Tariq, V. N. (2002). A decline in numeracy skills among bioscienceunder graduates. *Journal of Biological Education, 36*(2), 76-83.
The Royal Society. (2008). *Exploring the relationship between socioeconomic status and participation.*
United Nations Educational, Scientific and Cultural Organization (UNESCO). (2017). *Cracking the code: girls' and women's education in science, technology, engineering and mathematics uptake of physical science subjects: Some comparative case studies in England*. (STEM).
Wang, J. (2005). Relationship between mathematics and science achievement at the 8th Grade. *Online Journal of Science and Mathematics Education, 5*, 1-17.