ENGINEERING CAPITAL: A THEORETICAL AND EMPIRICAL MODEL OF ENGINEERING LEARNING, DIVERSITY AND PARTICIPATION

Rory McDonald*

University of Central Lancashire

Despite longstanding recognition and substantial investment, issues of poor diversity and inclusion continue to impact educational and career pathways for engineering. Given that solutions to global challenges such as the climate crisis are dependent on the engineering profession, we might see these issues of participation as an existential threat to our global resilience. Whilst engineering educational research traditionally focuses on further or higher education there is growing recognition that earlier experiences are vital in shaping identity and later participation with subjects such as engineering.

This paper introduces a new model of engineering participation to provide a fresh and pragmatic perspective on participation, diversity and inclusion. The model adopts a critical position to consider the deeper and unique characteristics of engineering and questions the utility of past approaches and pedagogies which assume that support for 'science' or 'STEM' will translate into support for engineering. This perspective considers engineering more keenly than previous approaches and identifies a richer array of learning experiences that shape later diversity of engineering participation including societal, historical, cultural, curricular, and non-curricular influences.

This model goes beyond simplistic descriptions of engineering diversity and inclusion to access the deeper underlying mechanics of influence that shape future engineers. Empirical evidence from over 900 secondary school-aged students in the UK is used to validate this model and identify what experiences shape the differing engineering aspirations of young people. These findings explore who are supported to become engineers and potential pedagogical reforms to widen participation.

Keywords: engineering learning, educational trajectory, learner resources, engineering pedagogy, engineering capital

**Correspondence to: C.O. Rory McDonald, Centre for Collaborative Learning, University of Central Lancashire, UK, PR1 2HE. Email: RAMcDonald5@uclan.ac.uk.*

1. INTRODUCTION

1.1 Engineering Skills Supply and Education

The United Kingdom, like many countries, faces entrenched engineering skills supply issues with an estimated deficit of 203,000 engineering-skilled workers each year (EngineeringUK, 2018). Given the important role engineering plays in the economy, and in addressing global issues such as the climate crisis, these skill deficits may be seen as threats to our global resilience and

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wellbeing. Addressing skill supply issues through the education of future engineers is therefore a topic of great importance.

Engineering education in the UK predominantly takes place as an elective subject in tertiary (further or higher) education and is largely absent from the compulsory curricula of primary and secondary education. This differs from the study of science which holds a prominent position in the compulsory curricula throughout primary and secondary education. This ‘science first, engineering later’ structure results in a less explicit presence of engineering in the lives of young UK learners who report significantly lesser understanding and interest in engineering compared to science (Hutchinson and Bentley, 2015). The lack of engineering during primary and secondary education is concerning given the recognition that these years are formative for a learner’s sense of identity towards subjects (Archer et al., 2020). The lesser presence of engineering during these years is also concerning given this period includes the first decision making opportunities that young UK learners use to shape their education. These early decisions shape the later options available in subsequent stages of elective education and so we may consider these formative experiences as deeply influential on the learner and their ‘educational trajectory’ through educational pathways.

Science and engineering share many characteristics but the distinct qualifications available for science and engineering and the lack of explicit engineering content within the UK curricula draws into question the degree to which young people are supported to aspire to engineering education under the current ‘science-first’ approach. It can be argued that whilst similar in abstract terms the subject areas of science and engineering involve distinct values, signature pedagogies and learning outcomes further questioning the impact of the ‘science first’ approach (Lucas and Hanson, 2016).

1.2 A Resources Perspective on Educational Trajectory

Little literature has examined support for engineering learning aspirations in the UK context, but a larger body of work has explored this for science. One dominant body of literature concerns the model of ‘science capital’ which considers the relationship between access to resources for science and desire to study or work in science roles. The science capital perspective is particularly interested in the unequal distribution of support for science aspirations in the population which contribute to inequity in science participation. A rich array of resources, or ‘capitals’, for science are considered in this model including cultural and social resources that may support a young person to place themselves on science educational trajectories (Archer et al., 2015).

Cultural resources considered by this model include knowledge, skills, or attitudes held by a young learner that support science learning and participation with science contexts and the culture of science. For example, understanding scientific terminology or the ways in which scientists behave are valuable resources that can support an individual in their learning experiences and their progress in science education. An individual lacking such resources will conflict with the practice of science and its culture, resulting in resistance in progress or underdeveloped interest. Social resources refer to resources that are available to an individual through their social network. For example, knowing someone who works in a science role may act as a resource in providing a role model or source of insight for studying or working in science to guide a young person on their science educational trajectory (Archer et al., 2015).

The science capital model has found great success in both theoretically and empirically investigating the relationship between science resources and aspirations for science offering a new perspective on science diversity, participation, and educational trajectories. The model has informed the improvement of science education in contemporary UK practice and led to the development of a novel 'science capital teaching approach'. Unfortunately, the science capital model does not explicitly explore resources for engineering and past research suggests that the model favours science over engineering questioning its relevance or accuracy for engineering (Moote et al., 2020). However, its wealth of findings for science educational trajectories suggest that a resource-based perspective is useful for understanding aspirations for the study of a particular subject. This introduces the potential for a model of engineering resources to better understand how young people are supported to aspire to engineering educational trajectories.

1.3 Forming a Theoretical Model of Engineering Trajectory Resources

This paper outlines, through a literature review and extrapolation from the science capital model, the development of a theoretical structure of resources for engineering learning. By forming a model of these resources practical understanding of engagement with engineering can be explored to support educators in evaluations of student learning and the design of effective pedagogies. Drawing on the science capital literature this engineering resource model considers seven different categories of resource or engagement with contexts in which resources may be developed. These resources are diverse and can be seen to reflect the holistic influence from cultural, social, historical, curricular and non-curricular sources within the life of the young learner. These seven categories of resources are outlined below:

- <u>Engineering Literacy</u>: Past literature acknowledges that a lack of subject knowledge plays a detrimental role in educational decision making (Marson-Smith et al., 2009). Models of literacy for engineering note that understanding engineering may refer to engineering-specific factual knowledge, an understanding of engineering methods and skills (such as creative problem solving or iterative design), or ways of embodying engineering thinking and behaviour (Grubbs et al., 2018). An understanding of engineering can be seen as a cultural resource that supports learning and may distinguish those aspiring to engineering education.
- <u>Engineering Attitudes</u>: Student attitudes towards a subject are well established as significant in both learning and educational decision making. Parental attitudes are also acknowledged as an influence on educational trajectory (White and Harrison, 2012). Positive attitudes amongst students and their parents might therefore be seen as another cultural resource that supports engineering educational trajectory and distinguishes future engineers.
- <u>Knowledge of Engineering Trajectories</u>: An understanding of the process to move through education and into engineering careers may be framed as a further cultural resource (Archer et al., 2015). Understanding how to move through educational trajectories to become an engineering professional is a resource for young learners that may distinguish those that wish to study engineering.
- <u>Knowing an Engineer</u>: Close social relationships, particularly familial relationships, are noted to influence trajectories towards engineering in the UK where 8.6% of engineers report having a parent who is an engineer – a much higher rate of intergenerational career choice than many other professions (Laurison et al., 2020).
- <u>Talking About Engineering</u>: Social interactions are well established as potentially advantageous for learning and educational trajectories (Jackson et al., 2019). Talking to others

about engineering represents a potential vehicle for learning and identity development that acts as a supportive resource for navigating engineering trajectories.

- Consuming Engineering Media: Few studies have examined the impact of consuming engineering media specifically, but in other contexts media consumption is established as a supportive resource for knowledge development (Penuel et al., 2010) and so may represent a valid resource for engineering educational trajectories.
- Engineering Learning Contexts: Given that engineering features so little in UK curricula the interaction with informal or 'out-of-school' learning contexts such as museums, after-school clubs, or hobbies involving engineering represent a form of resource to some individuals that supports aspiration to engineering education. Such engineering informal learning experiences are noted to influence engineering learning and likely influence the development of resources that support educational trajectories for engineering (Denson et al., 2015).

Having identified seven domains of resource for engineering that support aspirations for engineering education we can next examine these statistically to establish whether group differences exist in the resources of those who do or do not wish to study engineering in tertiary education. Understanding the distribution of engineering resources should inform strategies to better prepare young people for later engineering education and support greater aspiration for engineering trajectories. A resource-based perspective may also aid in addressing issues of poor diversity in engineering participation, as science capital has achieved for science. It is hypothesised that engineering resources are associated with engineering educational aspiration and that those who wish to study engineering in tertiary education will possess significantly greater resources.

2. METHODOLOGY

2.1 Methodology

A quantitative methodology was adopted to examine the degree to which young people who did or did not aspire to engineering education differed in their resources for engineering. A quantitative approach was chosen to maximise sample size. Secondary school-aged students were sampled as this group were expected to possess a more sophisticated understanding of engineering and would be making, or soon making, their first decisions for their educational trajectory.

2.2 Participants

A total of 921 secondary school-aged young people (ages 11 to 16) were recruited from 10 secondary schools in England and Scotland. Of this sample, 43% were boys and 57% were girls. Participants were recruited over the course of an academic year through opportunity sampling with schools contacted directly by the research team. Ethical approval was gained from a University of Central Lancashire ethics committee (BAHSS2 0141).

2.3 Instruments

A quantitative instrument was used to examine the independent variable (IV) of resources for engineering and the dependent variable (DV) of engineering educational aspiration. The IV measure included subscales for each of the seven forms of resource outlined in the theoretical model, totalling 39 items. Each subscale consisted of items from Archer et al.'s (2015) instrument of science capital adapted to focus on resources for engineering. Principal Components Analyses were used to confirm the dimensionality and validity of subscales and Cronbach's Alpha analyses confirmed their reliability (all subscales a<0.760). The instrument also included a single question on aspiration for future engineering education. Responses indicating a desire to study engineering after secondary education, including academic and vocational pathways in further education and the study of engineering at higher education were coded as 'aspiring to engineering education'.

2.4 Procedure

Schools in England and Scotland were contacted and offered the opportunity to engage with the research project. Once schools had consented to participation, print or digital materials were delivered to schools and students were offered the opportunity to participate. Those who agreed were asked to complete a questionnaire containing the IV and DV measures. Written guidance was provided to participants and teachers overseeing the data collection. Completed questionnaires were returned and analysed using the SPSS software. Cronbach's Alpha analyses confirmed the internal consistency of DV measures. Independent samples t-tests and a binary logistic regression analysis were completed on the dataset to investigate the differences in resource possession between groups of young people who did or did not aspire to engineering educational trajectories.

3. RESULTS

Independent samples Welch's t-tests were used to examine the differences in resources between groups that did (N=228, 26%) or did not wish to study engineering in tertiary education (N=659, 74%). Welch's t-tests were used due to unequal sample sizes. One t-test was used for each of the seven forms of resource identified in the theoretical model totalling seven t-tests. A Bonferroni adjustment was made to accommodate for the increased risk of Type 1 errors in multiple testing – a p-level adjustment was made from 0.05 to 0.007. Five of the seven Welch's t-tests identified significant differences in the resources of those who did or did not wish to study engineering in further or higher education. Two tests were rejected due to unequal levels of variance and sample size compromising interpretation. T-tests results are outlined in Table 1 below.

Type of Resource (Subscale Items/Range)	T-Test Result	Aspiration to Engineering Education Group Means	
		'Yes'	'No'
Engineering Literacy (six items: -12 to 12)	t(406.269)= -15.999, p<0.001, d=1.22	2.73	-1.84
Engineering Attitudes (seven items: -14 to 14)	t(428.902)= -10.830, p<0.001, d=0.80	4.85	-1.21
Knowledge of Engineering Trajectories (five items: -10 to 10)	t(407.565)= -11.774, p<0.001, d=0.89	2.87	-0.06
Consuming Engineering Media (four items: 0 to 16)	t(329.747)= -10.346, p<0.001, d=0.89	7.16	4.19
Engineering Learning Contexts (15 items: -2 to 50)	t(374.668)= -7.023, p<0.001, d=0.56	23.81	19.00

Table 1: Results of five Welch's independent t-tests examining group differences in engineering resource.

The seven t-tests reveal that those who aspire to engineering tertiary education possess significantly more engineering literacy, positive engineering attitudes, understanding of how to become an engineer, consume more engineering media, and engage with more informal learning experiences with engineering than those who do not wish to study engineering in tertiary learning. Knowing an engineer or talking with others about engineering could not be examined in this manner due to unequal variance in their measurement which compromised its statistical examination. Effect sizes were examined using Cohen's d calculation and found that engineering literacy, consumption of engineering media, knowledge of engineering trajectories and engineering attitudes all had strong ($d<0.8$) effects, whilst engaging in engineering learning contexts had a moderate (<0.5) effect.

Having established that significant differences exist between five types of engineering resource and desire to study engineering in tertiary education these resources were next integrated into a single model and tested through binary logistic regression analysis. This regression analysis examined whether each of the five types of resource contributed significantly to a predictive model for engineering educational aspiration. The binary logistic regression found that engineering literacy, knowledge of engineering trajectories, consumption of engineering media, and participation with engineering learning contexts were significant predictors of desire to study engineering in tertiary education ($X^2(5)=249.145$, $p<0.001$). The engineering attitudes predictor was not significant. The five predictors explained 36.0% of the variability in engineering educational aspiration (Nagelkerke R^2) and predicted 93.0% of those that did not wish to study engineering and 43.9% of those that did, resulting in overall accuracy of 80.4%.

4. DISCUSSION

Our t-test analyses demonstrated that those who aspire to engineering possessed significantly greater engineering resources confirming our hypothesis and highlighting the value of a resource-based perspective on trajectory towards tertiary engineering education. The significant differences established for five types of engineering resource (literacy, attitudes, knowledge of educational trajectories, media consumption and learning context participation) highlight the multidimensional distinctions that exist between secondary school-aged learners who do or do not aspire to engineering education. Given that engineering is largely absent from the UK national curricula the influence of these resources – many of which are sourced from outside the classroom – may be particularly significant for engineering. Understanding the impact of these resources on young learners may support efforts to address skills supply issues and develop future engineers.

The binomial regression analysis demonstrated the predictive power of a resource-based perspective on engineering educational trajectory. Whilst this first model possessed a somewhat limited accuracy (80.4% overall, but only identified 43.9% of those who wished to study engineering), it does demonstrate that resource provision offers a useful insight into the trajectory of young learners. Through a measurement of engineering resources our model could identify almost half of those who aspire to study engineering. The burden of solving engineering skill supply issues is often placed on educators, yet in many cases learners will not enter employment for some years (a first year secondary school learner will experience five to seven years of education before entering further or higher learning). Whilst the current model is not yet sufficiently accurate, through refinement the development of a predictive model for engineering tertiary education would represent a useful tool in understanding the flow of individuals through educational pathways and identifying future engineers.

Though it was not possible to empirically explore this deeply in the confines of this publication the resource-based perspective may also represent a valuable development in understanding the issues of diversity in engineering education and careers. The science capital model of science resources provided a sophisticated insight into differences in resources held by gender, ethnic, and socioeconomic groups (Archer et al., 2015). The analyses in this paper have confirmed that an engineering resources perspective is useful for examining group differences – in this case between those who do or do not wish to study engineering in tertiary education. Given the particularly strong inequities present within engineering (skewed to a male, White, middle class demographic) an understanding of the distribution of engineering resources may aid in understanding patterns of engineering aspiration and educational participation.

These findings suggest that resources for engineering have an influential effect in shaping young learners towards future engineering pathways. This would support the value of informal or curricular-mapped learning experiences that compliment the curricula and introduce engineering at younger ages. Such experiences could be perceived as providing engineering resources that support young people to engage with engineering pathways and become future engineers. The diverse forms of resource identified as significant in this analysis also supports the value of novel pedagogical approaches that bring engineering into classrooms. STEM integrative approaches, which introduce engineering content into curricular subjects such as science or mathematics, can take many forms depending on the content and context used to support engineering learning. Our analysis suggests that even the introduction of implicit resources such as engineering literacy or the use of rich media containing engineering in other subjects should support greater aspiration to improve students' engineering education trajectories. These findings support that curricular reform for engineering could focus on integrating engineering resources into existing subject areas.

Our results also highlight the importance of public engagement efforts conducted by higher education institutions that introduce engineering learning experiences to members of the public. Outreach with younger public groups might be framed as a vehicle to support resource development in pre-tertiary education. Approaches to public engagement with engineering may benefit from clearer planning and learning outcomes for engineering resources given the recognition that these resources are associated with greater aspiration for engineering education.

Whilst this study only represents a preliminary investigation of how forms of resource for engineering can be holistically examined in a population the findings support the validity and usefulness of a resource-based perspective on engineering educational aspiration. Further study of the distribution and impact of engineering resources with more complex methodological designs would facilitate a deeper understanding of the causal influence of engineering resources on educational trajectories for engineering. Although the predictive power of our preliminary model is somewhat low, this theoretical and empirical investigation is a valuable proof of concept that suggests a model of 'engineering capital' could offer a novel lens on issues of engineering participation, progression and skills supply in the UK context.

5. REFERENCES

Archer, L., Dawson, E., DeWitt, J., Seakins, A. and Wong, B., 2015. "Science capital": A conceptual, methodological, and empirical argument for extending bourdieusian notions of capital beyond the arts. *Journal of research in science teaching*, 52(7), 922-948.

Archer, L., Moote, J., MacLeod, E., Francis, B., and DeWitt, J., 2020. ASPIRES 2: Young people's science and career aspirations, age 10-19. London: UCL Institute of Education.

Denson, C., Lammi, M., White, T.F. and Bottomley, L., 2015. Value of informal learning environments for students engaged in engineering design. *Journal of Tech. Studies*, 41(1), 40-46.

EngineeringUK, 2018. Engineering UK 2018: The state of engineering. URL: https://www.engineeringuk.com/media/156187/state-of-engineering-report-2018.pdf

Grubbs, M.E., Strimel, G.J. and Huffman, T., 2018. Engineering education: A clear content base for standards. *Technology and Engineering Teacher*, 77(7), 32-38.

Hutchinson, J. and Bentley, K., 2015. STEM subjects and jobs: A longitudinal perspective of attitudes among Key Stage 3, 2008–2010. Derby: International Centre for Guidance Studies.

Jackson, M.C., Leal, C.C., Zambrano, J. and Thoman, D.B., 2019. Talking about science interests: the importance of social recognition when students talk about their interests in STEM. Social Psychology of Education, 22(1), 149-167

Laurison, D., and Friedman, S., 2020. The Class Ceiling: Why it Pays to be Privileged. Bristol: Policy Press.

Lucas, B. & Hanson, J., 2016. Thinking Like an Engineer: Using Engineering Habits of Mind and Signature Pedagogies to Redesign Engineering Education. *International Journal of Engineering Pedagogy*, 6(2), 4-13.

Marson-Smith, H, Golden, S., and McCrone, T., 2009. Widening 14-19 choices: support for young people making informed decisions. URL: https://www.nfer.ac.uk/media/2179/smd01.pdf

Moote, J., Archer, L., DeWitt, J. and MacLeod, E., 2020. Science capital or STEM capital? Exploring relationships between science capital and technology, engineering, and maths aspirations and attitudes among young people aged 17/18. *Journal of Research in Science Teaching*, 57(8), 1228-1249.

Penuel, W.R., Bates, L., Pasnik, S., Townsend, E., Gallagher, L.P., Llorente, C., and Hupert, N., 2010. The impact of a media-rich science curriculum on low-income preschoolers' science talk at home. ICLS.

White, E.L. and Harrison, T.G., 2012. UK School Students' Attitudes towards Science and Potential Science-Based Careers. *Acta Didactica Napocensia*, 5(4), 1-10.