Factors Affecting whether Students in England Choose to Study Physics once the Subject is Optional

Tamjid Mujtaba[1] and Michael J. Reiss[2]

Institute of Education, University of London, London, UK

NARST March 2012, Indianapolis, USA

Abstract

This paper is based on the longitudinal quantitative strand of a large-scale mixed methods ESRC-funded study, 'Understanding Participation rates in post-16 Mathematics And Physics' (2008-2011); the project sought to identify factors that relate to students' intended choices with respect to physics and mathematics. This paper investigates issues around physics choice at age 16 in post-compulsory education; we followed our original 2008 year 10 cohort (4983 students who were aged 15) who filled out a physics survey in the academic year 2008-2009 in our English schools into year 12 (academic year 2010-2011). This longitudinal sample consists of 1749 students (709 male and 1040 female).

Background and framing

Worldwide, there is still a shortage of studies in mathematics and science education that examine student engagement over time and research the reasons for the take up or non take up of mathematics and science at the point at which these subjects become optional. Much remains to be done to understand what drives student subject choice once subjects become optional (Blenkinsop *et al*., 2006; Gill *et al*., 2009). Of the sciences, we concentrate on physics. In part this is because of the severity of the problems: both in the UK and in a number of other countries these include a persistent shortage of specialist physics teachers and a continuing decline in the percentage of the school cohort that chooses to study physics 'post-16' (a term that we use as a shorthand for 'post-compulsory' as physics, within science, is compulsory for students in the UK until this point). In England at the age of 16, students typically take General Certificate of Secondary Education (GCSE) examinations in about eight to twelve subjects, with limited student choice. Post-16 academic courses usually take the form of Advanced Level (A-Level) examinations taken at age 18 in about two to four subjects with a great deal of student choice. In order to do physics at A-Level, students in England, Northern Ireland and Wales (Scotland has a different examination system) are typically required to get a high grade (A*, A or B) in GCSE science or physics. The number of students entering physics A-Level has begun to see a rise over the past five years, having reached a low in 2006 but even so the number of students continuing with physics post-16 is still

1 Email: t.mujtaba@ioe.ac.uk
2 Email: m.reiss@ioe.ac.uk

only slightly over half of what it was in 1982. In 2010 (during the mid-point of this study), physics entrees only constituted 3.6% of the entire cohort sitting A Levels, with 6.2% of males who sat A-Levels having taken physics compared to only 1.4% of females who sat A-Levels.

Our approach presumes that once students are no longer required to do certain subjects, participation in such subjects depends at least in part on how students see both themselves and the subjects. Neither of these is fixed. Each can shift as a result of experiences both inside and outside the classroom (Black *et al.*, 2009). When students encounter school mathematics and physics, they respond to them in a variety of ways. Understanding the reasons for these varied responses may help make sense of the particularities of how different students react to mathematics and physics and of the phenomenon, widely found in industrialised countries, in which many of those who do well at school in mathematics and the sciences reject them (Nardi & Steward, 2003; Schreiner, 2006). Identification with the meaningfulness of mathematics / physics is partly the result of such cultural forces but it is the individual's affective response, both conscious and unconscious, that ultimately attracts, or fails to attract, each person to the subject (Reiss, 2005; Brown *et al*., 2008; Rodd *et al*., 2010). Unless there is sufficient positive connect between a student's developing sense of self and the meanings they find in mathematics / physics, the student-subject relationship may not flourish but atrophy or become one of antagonism. Of course, such individual factors do not operate in isolation from other factors, for example those operating at the level of schools or society more generally. The methodology for our project is therefore designed to help us investigate and, so far as possible, untangle the relationships between the various factors operating at various levels.

There are specific concerns within physics education such as students from particular ethnic backgrounds being less likely to engage in physics/science (Dewitt *et al*., 2011) and the age old issue of the gender gap in the uptake of physics which is a continuous and established problem at secondary school, further education and higher education levels (Blickenstaff, 2005; Murphy and Whitelegg, 2006; JCQ, 2011). We have explored gender issues in physics uptake elsewhere (Mujtaba & Reiss, forthcoming) though this paper is more concerned with factors (that influence choice, changes in perceptions/choice) which schools and education policy can do something about.

Methodology

Our study comprises three strands, one of which is quantitative and two of which are qualitative. This paper is based on the quantitative strand 'Mapping trajectories of engagement and disenchantment'. In this strand, we obtained a sample of 141 schools across the UK that would agree to work with us by having year 8 (12-13 year-olds) and year 10 (14-15 year-olds) students complete a student questionnaire about themselves, their conceptual understanding of mathematics / physics and their views of the subject. As many as possible of the year 10 students were then contacted two years later (year 12) and asked to fill out a new, single questionnaire that covered both mathematics and physics.

Whilst there is abundant literature pertaining to extrinsic factors affecting choices and achievement, comparatively little has been reported on the relationship between intrinsic factors, such as personality and attitudes to, and achievement in, mathematics and science and their relationships to subject choice, achievement and post-16 participation. Accordingly, we designed student questionnaires to include items from established psychological constructs alongside validated subject-specific conceptual tasks so that possible relationships between performance, confidence and intrinsic and extrinsic factors could be explored in each subject and across the two subjects. Mindful of criticisms (e.g. Blalock *et al.*, 2008) that science attitude surveys typically possess weak psychometric properties, a high proportion of the items for the student questionnaire were taken from well-validated constructs in the literature that it seemed reasonable to hypothesise might be related to participation / intention to participate in mathematics and/or physics post-16. In addition, much of the research in science attempts to explain factors that shape engagement with physics focuses on school influences, personal attributes or home influence, rather than taking a holistic approach; our research takes a more holistic approach, acknowledging that students are influenced by a range of social influences as well as their own values. Another problem with research to date is that research on physics issues is typically subsumed into research on science issues. UPMAP overcomes this problem as the research instrument (a questionnaire) on which we draw in this paper contained 130 physics-specific items rather than more general items relating to science.

The student questionnaires went though about five rounds of design and piloting and we ended up with four versions: one for year 8 students and focusing on mathematics; one for year 8 students and focusing on physics; one for year 10 students and focusing on mathematics; one for year 10 students and focusing on physics. The findings from successive rounds of piloting meant that a number of the items were reworded so as to make them easier to understand for these age ranges. In addition, we included a number of items in our piloting (e.g. use by students of new digital technologies) because we thought it reasonable to presume that there might be a causal relationship between them and participation / intention to participate and certain items within constructs were omitted or re-worded. The result was that all constructs in the final versions of the questionnaires had Cronbach alphas of between 0.6 and 0.9. Subsequently, we ran confirmatory factor analyses which confirmed the great majority of the constructs but also led to some changes (e.g. a redistribution of certain items between the constructs ‘attitudes to lessons’ and ‘perceptions of lessons’).

Our sampling of students was influenced by the project aims – we targeted students who were predicted to get grades A*-D in GCSE mathematics and physics/science (which corresponds to approximately the top two-thirds of students in terms of attainment). Although all barriers to participation are important, we are particularly interested in factors that affect the ‘choices’ of those students who have the opportunity, including fulfillment of attainment criteria, to study physics (or mathematics) post-16. Such a sample has a bearing on the types of associations we find and report.

Analysis

Our analysis of the quantitative strand was undertaken using multivariate methods (multilevel modelling) as well as exploring the data using bivariate and univariate analyses. Multilevel modelling has existed for many decades but its use has taken off in education in the last 20 years or so partly because of the increasing availability of computing power and (fairly) easy to use multilevel modelling software (notably MLwiN, 2009) and partly because the approach has successfully been used in a number of large and influential studies (e.g. Goldstein *et al*., 2007). Multilevel modelling can be conceptualised as a particular instance of multiple analysis of variance in which certain restrictions are placed, in advance of the analysis, on the organisation of the dependent variables (in this it differs from factor analysis and principal component analysis). In the paradigmatic case in education, features of individual students (e.g. attainment) are seen as resulting from a hierarchy of effects beginning at the individual student level and then scaling up through successive rungs of a hierarchy, e.g. student class, student school, school area. In the case of this project the lowest (most fine-grained) level of the hierarchy is the individual student and the next level is the school. In common with other studies that use multi-level modelling we find below that student factors are substantially more important than school factors as explanatory variables.

In the absence of experimentation (e.g. as provided by randomised controlled trials) multilevel modelling, of course, provides evidence for causation through correlations whose likely importance is indicated by effect sizes, quantification of interactions and by the extent to which emerging conclusions fit into (or extend) well-grounded theories.

Results

We followed as many as possible of our original sample of 4983 students who filled out a physics survey at year 10 in the academic year 2008-2009 in our English schools into year 12 (academic year 2010-2011). This longitudinal sample consists of 1749 students (709 male and 1040 female). Of these 1749 students, 556 had stated in year 10 that they would not continue with physics post-16, 493 had expressed an intention to continue and 700 did not give a response.. In terms of actual physics choices in year 12, 441 students chose physics, 1282 chose not to do physics and 26 did not give a response.

The sub-set of 493 students who had 'strongly agreed' to study physics post-16 in 2008

We compared the survey responses of two groups of students who had ticked 'Strongly agree' in year 10 on a six-point scale in response to the statement 'I intend to continue to study physics after my GCSEs': those that had chosen to do physics post-16 and those who had not. The intention behind this analysis was to have a particular focus on differences in students' aspirations/perceptions of their physics education some two years later – when they had two years earlier all been at the 'same' starting point, i.e. strongly agreeing to continue with physics post-16.

We found that there were statistically significant differences in responses, with those who chose to do physics responding more positively to the following physics-specific constructs: self-concept, perception of lessons, emotional response to lessons, advice-pressure to study physics, intrinsic motivation in physics, extrinsic material and social gain motivation, perceptions of physics teachers and home support in physics learning. All differences referred to are statistically significant at $p < 0.01$.

The relationship between constructs measuring 'physics education' in 2011 compared to 2009

We conducted correlation analysis in order to explore the relationship between students' perceptions of their physics education in 2009 compared to 2011. The strongest association over the two years was the physics self-concept followed by students' extrinsic value of physics. Further details about how changes in these two constructs pan out are detailed in figures 1 and 2 below. There was a statistically significant association between students' perceptions of their physics education at year 12 compared to year 10 for the following physics-specific constructs: physics self-concept (r=.505 p<01); extrinsic material gain motivation (r=.414 p<01); intrinsic value of physics (r=.409 p<01); perceptions of physics lessons (r=.380 p<01); home support for achievement in physics (r=.379 p<01); advice-pressure to study physics (r=.344 p<01); perceptions of physics teachers (r=.329 p<01) and emotional response to physics lessons (r=.289 p<01). However, these associations are not strong and this suggests that there are considerable changes in perceptions over the two years.

Table 1 displays the 'changes in perceptions' scores from 2009 to 2011. A score of 0 indicates that there were no changes in responses; scores above 0 are equivalent to positive changes, whereas scores below 0 indicated negative changes in perceptions. The table indicates that though students' intrinsic and extrinsic motivation/value of physics increased over the years, their perceptions of their physics education (lessons, self-concept and teachers) saw a decrease.

Table 1: Changes in students' perceptions of their physics education between 2009 and 2011

	N	Mean	Std Dev.	Variance
	Valid			
NEGATIVE CHANGES IN STUDENTS PERCEPTIONS OF THEIR PHYSICS EDUCATION				
Physics choice change	1034	-.1896	.54324	.295
Changes in self-concept	1047	-.2793	1.09048	1.189
Changes in perceptions of physics lessons	975	-.0366	1.19648	1.432
Changes in emotional response to physics lessons	970	-.1491	1.21552	1.477
Changes in perceptions of physics teachers	976	-.0883	1.17348	1.377
Changes home support achievement in physics	872	-.2058	1.24069	1.539
POSITIVE CHANGES IN STUDENTS PERCEPTIONS OF THEIR PHYSICS EDUCATION				
Changes in advice-pressure to study physics	1014	.1631	1.48996	2.220
Changes in intrinsic value of physics	1032	.1099	1.04935	1.101
Changes in extrinsic material gain motivation	1040	.1850	1.09313	1.195
Changes in extrinsic social gain motivation	912	.4755	1.23664	1.529

Figures 1 and 2, display the frequencies of the self-concept and extrinsic value of physics. Despite these two constructs having the strongest association between perceptions in 2011 compared to 2009, in general perceptions of the physics self-concept has declined whereas the intrinsic value of physics has increased.

Figure 1: Changes in students' perceptions of the physics self-concept

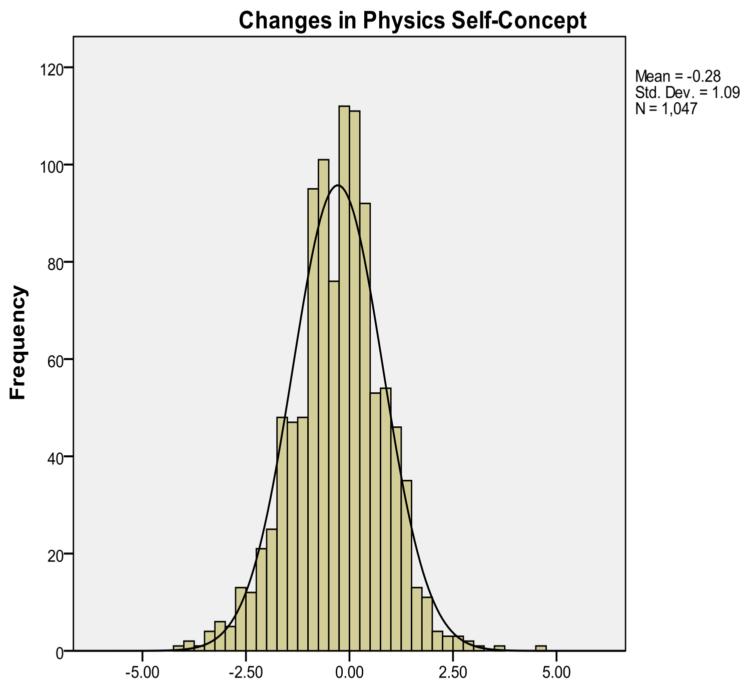
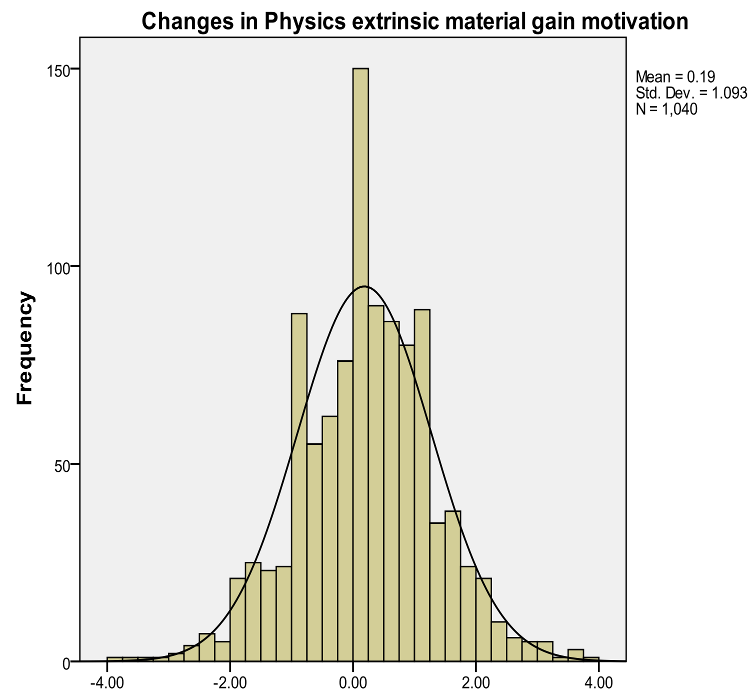


Figure 2: Changes in students' perceptions of the physics extrinsic value



Exploring factors that influence students' choice in physics at year 12

Physics choice model

We undertook multilevel modelling to explore the factors that influence physics choice at post-compulsory education – in the first year of A Levels.

Ability: We found that current conceptual ability and prior attainment were not important in explaining physics participation in the final model once we controlled for attainment at GCSE (in physics/sciences), extrinsic motivation and home support for achievement in physics.

Support: Furthermore, home support for achievement in physics, though it does not have a high effect size (ES = 0.8), does nevertheless have an influence above and beyond current conceptual ability and prior attainment. In addition, advice-pressure to study physics (ES = 2.1) – which is a construct that taps into influences from school and home – is related to actual physics uptake. These two findings indicate that encouragement from others both in and out of the school are associated with students opting to study physics.

Students' background characteristics: As would be expected (given that only about one in five post-16 participants in physics are girls, and that those on free school meals [a measure of low socio-economic status] are less likely to study any subject post-16), girls in non-selective schools were less likely to choose physics in year 12 than white boys not on free school means and Asian boys not on free school meals.

School composition: The physics attainment level of schools is associated with students opting to do physics, with those schools with higher averages in physics attainment at age 16 more likely to have students who go on to study physics.

Self-concept and motivation: In the physics intended participation models (i.e. modelling undertaken solely on the responses to the year 10 questionnaires), physics self-concept did not have an independent influence in explaining stated intention to participate, particularly after controlling for the influence of physics extrinsic material gain motivation (ES = 3.1) and advice-pressure to study physics. However, in our actual participation models (i.e. using data from year 12), physics self-concept (ES = 0.9) has a significant independent influence.

Mathematics: Our multi-level models indicated that even after controlling for all of the above factors, students choosing to study mathematics in year 12 is significantly associated with students studying physics in year 12.

Physics change model

This model explored the factors that shaped students' changes in intentions to study physics over two years (the changes demonstrated in table 1). The 2009 intention to participate score was turned into a dichotomous variable in order to make comparisons with actual choice. We created a change score in perceptions and attitudes from 2009 to 2011 for each of the constructs (as discussed earlier). Changes in perceptions/attitudes in the following constructs were unrelated to change in physics participation: perceptions of teachers, perceptions of lessons, physics self-concept, social support in physics learning, intrinsic value of physics and extrinsic motivation social gain. We explored the relationship between changes in intention to study mathematics and changes in intention to study physics; there was no statistically significant relationship. Changes in the following constructs were related to changes in physics choice over two years: physics emotional response to lessons (ES = 2.1), physics extrinsic material gain (ES = 2.9) and advice-pressure to study physics (ES = 3.1). Changes in home support for achievement in physics was not a significant predictor of physics choice though only just failed significance (post the introduction of advice-pressure to study physics). Finally, gender was not a significant predictor of change in physics choice.

The relationship between mathematics and physics: exploring responses between year 10 and year 12 students

A series of correlation analysis and t-tests were conducted in order to explore the relationship between mathematics and physics and how such associations change from year 10 through to year 12. Our interest in the relationship between mathematics and physics predominantly arose out of our finding of the importance of mathematics in explaining physics participation (in line with other work conducted in this area). All of the reported findings are significant at $p < 0.01$.

Physics and mathematics lessons

Our analyses indicate that there was a statistically significant association between students' perceptions of mathematics and physics lessons at year 12 ($r=.558$, $p<01$), with the association being higher than it was in year 10 ($r= .391$, $p<01$). Further analyses conducted in order to test for differences in perceptions of mathematics and physics lessons revealed the differences were significantly different, with students holding more positive perceptions of mathematics lessons in both year groups.

There was a statistically significant association between students' responses in their perception of mathematics and physics lessons at year 12 (.558) with the association being higher than it was for these same students in their year 10 responses in 2008 (.391, $p<01$). Further analyses (t-tests) conducted in order to test for differences in perceptions of mathematics and physics lessons revealed the differences were statistically significant ($t=13.495$, $p<.001$), with students holding more positive perceptions of mathematics lessons.

There was a statistically significant association between students' in their emotional response to mathematics and physics lessons at year 12 (.663, $p<.01$) and these associations were higher for these same students compared to their earlier year 10 associations (.368, $p<.01$). Further analyses conducted in order to test for differences in their emotional responses to mathematics and physics lessons revealed the differences were statistically significant ($t=8.769$, $p<.001$), with students having more positive emotional responses to mathematics lessons.

There was a statistically significant association between students' perceptions of their mathematics and physics teachers at year 12 (.402, p<.01) and these associations were higher for these same students compared to their earlier year 10 associations (.241, p<.01). Further analyses conducted in order to test for differences in perceptions of their mathematics and physics teachers revealed the differences were statistically significant (t=12.093, p<.001), with students reporting more positive perceptions of mathematics teachers.

Support for learning

There was a statistically significant association between students' perceptions of 'advice-pressure to study mathematics and physics' post-16 at year 12 (.690, p<.01) and these associations were higher for these same students compared to their earlier year 10 associations (.425, p.<.01). Further analyses conducted in order to test for differences in perceptions of 'advice-pressure to study mathematics and physics' post-16 revealed the differences were statistically significant (t=24.785, p<.001), with students reporting more 'advice-pressure to study maths' post-16. There was a statistically significant association between students' responses in their perceptions of 'home support for achievement in mathematics and physics' for year 12 students (.821, p<.01) and these associations were higher for these same students compared to their earlier year 10 associations (.576, p.<.01).

Motivation (extrinsic and intrinsic)

There was a statistically significant association between students' perceptions of mathematics and physics 'extrinsic material gain motivation' at year 12 (.667, p<.01) and these associations were higher for these same students compared to their earlier year 10 associations (.442, p<.01). Further analyses conducted in order to test for differences in this construct revealed the differences were statistically significant (t=30.389, p<.001), with students reporting higher levels of mathematics extrinsic material gain motivation.

There was a statistically significant association between students' perceptions of mathematics and physics 'extrinsic social gain motivation' at year 12 (.927, p<.01) and these associations were higher for these same students compared to their earlier year 10 associations (.496, p<.01). Further analyses conducted in order to test for differences in this construct revealed the differences were statistically significant different (t=5.980, p<.001), with students reporting higher levels of mathematics extrinsic social gain motivation.

There was a statistically significant association between students' perceptions of mathematics and physics 'intrinsic motivation' at year 12 (.650, p<.01) and these associations were higher for these same students compared to their earlier year 10 associations (.479, p<.01). Further analyses conducted in order to test for differences in this construct revealed the differences were statistically significant (t=1.409, p<.001), with students reporting higher levels of mathematics intrinsic motivation.

Ability and cognition

There was a statistically significant association between students' perceptions of their mathematics and physics self-concept at year 12 (.597, $p<.01$) and these associations were higher for these same students compared to their earlier year 10 associations (.506, p.<.01). Further analyses conducted in order to test for differences in this construct revealed the differences were statistically significant ($t=16.713$, $p>.001$), with students reporting higher levels of mathematics self-concept.

There was a statistically significant association between students' conceptual understanding of mathematics and physics at year 12 (.214, $p<.01$) and these associations were higher for these same students compared to their earlier year 10 associations (.160, p.<.01). Further analyses conducted in order to test for differences in this construct revealed the differences were statistically significant ($t=27.285$, $p<.001$), with students reporting higher levels of conceptual understanding of mathematics.

There were statistically significant associations between students' confidence in their ability in their conceptual mathematics and physics tasks in year 8 (.448, $p<.01$) and year 10 (.468, p.<.01). Further analyses conducted in order to test for differences in this construct revealed the differences were statistically significant ($t=20.087$, $p<.001$), with students reporting higher levels of confidence in conceptual understanding of mathematics.

There was a statistically significant association between students' attitudes towards mathematics and physics conceptual tasks in year 8 (.586, $p<.01$) and year 10 (.510, p.<.01). Further analyses conducted in order to test for differences in this construct revealed the differences were statistically significant ($t=12.274$, $p<.001$), with students reporting higher levels of conceptual understanding of mathematics.

Discussion

Recent research into the reasons why students do or do not choose to study mathematics or science, once they get the choice, is increasingly focusing on issues to do with student identity. For example, Taconis & Kessle (2009, p. 1115) proposed "that the unpopularity of science in many industrialised countries is largely due to the gap between the subculture of science, on the one hand, and students' self image, on the other". They undertook a study with Dutch ninth-grade students and found that "Dutch students see typical peers who favour science subjects (physics/biology) as less attractive, less popular and socially competent, less creative and emotional, and more intelligent and motivated than typical peers who favour humanities subjects (economics/languages)" (p. 1128), a similar finding to an earlier one in Germany (Hannover & Kessels, 2004). Such studies encourage us in our assertion that issues of student identity need to be considered when attempting to understand issues of student participation and subject choice.

Our findings indicate the importance of how students see themselves in relation to physics as a key factor in correlating with whether or not students study physics post-16. Physics self-concept, i.e. the psychological construct that indicates how a student sees themself in relation to the subject physics, had a significant independent relationship with whether or not a student was studying physics post-16. Other factors that were important in correlating with post-16 participation include participation in mathematics, how students see their physics teachers, home support for achievement in physics and advice-pressure to study physics. Our findings suggest that changes in students' perceptions of their physics education in the final years of compulsory education is crucial in its relationship to choice – as well as students' engagement and relationship with physics.

References

Black, L., Mendick, H. & Solomon, Y. (Eds) (2009). *Mathematical relationships in education: Identities and participation*. London: Routledge.

Blalock, C.L., Lichtenstein, M.J., Owen, S., Pruski, L., Marshall, C. & Toepperwein, M. (2008). In pursuit of validity: a comprehensive review of science attitude instruments 1935-2005. *International Journal of Science Education, 30*, 961-977.

Blickenstaff, J. (2005). Women and science careers: leaky pipeline or gender filter? *Gender and Education, 17*(4), 369-386.

Blenkinsop, S., McCrone, T., Wade, P. & Morris, M. (2006). *How do young people make choices at 14 and 16? Research Report 773*. Nottingham: DfES.

Brown, M., Brown, P. & Bibby, T. (2008). "I would rather die": reasons given by 16-year-olds for not continuing their study of mathematics. *Research in Mathematics Education, 10*, 3-18.

Gill, T., Vidal Rodeiro, C.L. & Bell, J.F. (2009). The complexities surrounding the uptake of A-level Physics. Paper presented at the British Educational Research Association Annual Conference, Manchester University, September 2009.

Goldstein, H., Burgess, S. & McConell, B. (2007). Modelling the effect of pupil mobility on school differences in educational achievement. *Journal of the Royal Statistical Society, Series A, 170*, 941-954.

Hannover, B. & Kessels, U. (2004). Self-to-self prototype matching as a strategy for making academic choices. Why high school students do not like math and science. *Learning and Instruction, 14*, 51-67.

JCQ (2011). Examination results: A-levels, http://www.jcq.org.uk/national_results/alevels/ (last accessed 13th November 2011).

MLwiN (2009). *MLwiN: A software package for fitting multilevel models.* Bristol: Centre for Multilevel Modelling, University of Bristol. http://www.cmm.bristol.ac.uk/MLwiN/index.shtml.

Mujtaba, T., & Reiss, M. J. (forthcoming). What sort of girl wants to study physics after the age of 16? Findings from a large-scale UK survey. *International Journal of Science Education*.

Murphy, P. & Whitelegg, E. (2006). *Girls in the Physics Classroom: A review of the research on the participation of girls in physics.* London: Institute of Physics.

Nardi, E. & Steward, S. (2003). Is mathematics T.I.R.E.D? A profile of quiet disaffection in the secondary mathematics classroom. *British Educational Research Journal*, *29*, 345-366.

Reiss, M.J. (2005). The importance of affect in science education. In S. Alsop (Ed.), *Beyond Cartesian Dualism: Encountering affect in the teaching and learning of science* (pp. 17-25). Dordrecht: Kluwer.

Rodd, M., Mujtaba, T., & Reiss, M. J. (2010). Participation in mathematics post-18: undergraduates' stories. *British Society for Research into Learning Mathematics, 30*, 175-182.

Schreiner, C. (2006). *Exploring a ROSE-garden: Norwegian youth's orientations towards science – seen as signs of late modern identities*. Oslo: Faculty of Education, University of Oslo.

Taconis, R. & Kessels, U. (2009). How choosing science depends on students' individual fit to 'science culture'. *International Journal of Science Education*, *31*, 1115-1132.