Leading education and social research
Institute of Education
University of London

20 Bedford Way
London WC1H OAL
Tel +44 (0)20 7612 6000
Fax +44 (0)20 7612 6126
Email info@ioe.ac.uk
www.ioe.ac.uk

Contents

Understanding Participation rates in Post-16 Mathematics And Physics (UPMAP)

The UPMAP project is research will identify the key factors that shape patterns of participation in post-16 mathematics and physics taking account of differences between schools as well as individuals.

We will:

1. Map trajectories of engagement and disenchantment by analyses of large scale and longitudinal statistical data that encompass engagement with core areas of knowledge as well as attitudes. We will gather data from a student questionnaire at two points, two years apart, in each of a large number of schools across the UK.

2. Investigate subjectivities and school culture by focusing on schools that have different staying-on rates in mathematics and physics and work with teachers to ascertain reasons for high staying-on rates. We will work with 12 of our strand 1 schools in more depth, conducting interviews and observations in each school over a two-year period.

3. Document reasons for HE choices by asking students in their first year of university about their choice of degree course to identify examples of serendipitous events and critical incidents that have shifted students from anticipated trajectories. We will recruit 50 students, half of whom have started degree courses in accountancy, mathematics, engineering or physics and half of whom have started other degree courses.

Background and framing

Much of the research in mathematics and science education in the UK since the 1970s has focused on ways of understanding the factors that inhibit or enhance classroom learning (cf. Noss & Hoyles, 1996; Millar et al., 2006). However, there is a shortage of studies that examine student engagement over time and research the reasons for the take up or non take up of both mathematics and science. UK research has taken place alongside government initiatives to raise attainment and a growing acknowledgement that there is a problem in participation rates post-16[1] in chemistry, mathematics and physics both in the UK and elsewhere, particularly in industrialised countries (Gilbert, 2006; OECD, 2006). These initiatives have been triggered because of economic concerns about the national implications of a deepening shortage of chemists, mathematicians and physicists (e.g. HM Treasury, 2004).

Much remains to be done to understand what determines student attitudes towards mathematics and science (Osborne et al., 2003; Lord & Jones, 2006) and what drives student subject choice post-16 (Blenkinsop et al., 2006). We concentrate on physics, in part because of the severity of the problems, in part because of the historically (many would argue contingently) close links between physics and mathematics (cf. Carson, 1999). In addition, the profile of student participation in physics and mathematics is similar, as is the shortage of specialist teachers.

In the light of this we find it surprising that little work has been undertaken, so far, to examine the extent to which the issues affecting student attitudes and subject choice are or are not common to mathematics and physics – indeed, any part of science. One exception is the study by Bradshaw (2007) in which it was found that it was easier for advanced level students to see applications to real life in the sciences than in mathematics – a factor which was thought to encourage student participation in the former. Throughout the project we will investigate the similarities and differences between mathematics and physics with regard to factors affecting student attitudes and subject choice.

The aim of this study is to deepen our understanding of what attracts some students to mathematics and to physics and what drives others away. Knowing the factors that shape student engagement and choices will provide advice to policy makers to decide how to engage more students in these subjects by targeting interventions and new approaches to pedagogy (cf. Boaler, 1997; Murphy & Whitelegg, 2006). When students encounter school mathematics and physics, they respond to these discourses in a variety of ways. Understanding the reasons for these varied responses can help make sense of many of the ways in which different students (e.g. females and males) react differently 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 (Schreiner, 2006).

In this project, school subjects will be conceptualised as special types of discourses (Harré & Gillett, 1995; Sfard & Prusak, 2005; Mendick, 2006). Part of our work, therefore, is grounded in a different language from that generally used in the analysis of ‘the problem of uptake in mathematics and physics’, and wider, social and cultural forces will be considered as well as individual issues to do with understanding and affect. We are open to a framing in which students respond to curricula, to pedagogies and to subject representations outside of schools (e.g. in films and magazines, on TV, in everyday conversations) by partial negotiations, both of their own identities and of mathematics / physics. This identification with the meaningfulness of mathematics / physics is partly the result of such cultural forces but it is the individual's emotional response that ultimately attracts, or fails to attract, each person to the subject. 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.

While looking for factors that encourage or undermine students' willingness to engage with school mathematics and physics, we will consider (1) the nature of the subjects themselves with particular attention to discontinuities in their development, (2) the way these subjects are developed by curricula and teaching, and specifically through targeted interventions, (3) the significance of these discourses for students' developing identities, and (4) the sensitivity of existing curricula to the differing needs of the students.

For the first issue, we will draw on research on misconceptions and on conceptual change (Smith et al., 1993; Schnotz et al., 1999). The re-interpreted findings of this research will help in identifying critical junctures where many students are likely to be left behind or lose interest, unless provided with special assistance.

For the second issue, we will draw on what is known about what makes mathematics and physics meaningful to different groups of students. Meaningfulness will be conceived as an ability to appreciate how concepts yet to be learned are related to those that are already familiar or of value to the student either from previous school learning or from everyday life. Although this interpretation of the term is broader than the one that equates meaningfulness with real-life relevance, our stress on the importance of the developmental continuity is grounded in research that has shown the superiority of people's everyday mathematical performance over their performance while faced with seemingly equivalent school problems (Lave, 1988; Walkerdine, 1988; Nunes et al., 1993; Zohar, 2006). We will therefore consider the role of interventions in giving meaning in this broad sense to school-based work.

In analysing students' developing identities, we will build on existing research on student attitudes towards mathematics and science as well as on research on learning and values (Bishop, 2001) and affect (Reiss, 2005).

A related presumption of ours is that recent curriculum reforms in school mathematics and science, including physics, have failed adequately to take account of student diversity. In schools both mathematics and physics are marked by a wide range of attainment yet the two subjects differ greatly in curriculum diversity, particularly at KS4 where the mathematics intended curriculum is substantially more constrained that that available in science. Our assumption is that what is needed alongside any curriculum change that takes account of attainment spread in these two subjects are ways to enable teachers to be aware of and even exploit student diversity by offering a range of pedagogical approaches and targeted interventions, about which this research will offer evidence-based guidelines.

References

Bishop, A. J. (2001) In F. L. Lin & T. Cooney (Eds), *Making Sense of Mathematics Teacher Education*, Kluwer, pp. 233-246.

Blenkinsop, S., McCrone, T., Wade, P. & Morris, M. (2006) *How Do Young People Make Choices at 14 and 16?*, Research Report 773, DfES.

Boaler, J. (1997) *Experiencing School Mathematics*, Open University Press.

Bradshaw, N.-A. (2007) *Enabling Trinity to Produce 'More Maths Grads'*, University of Greenwich.

Carson, S. (1999) *Shaping the Future: Physics in mathematical mood*, Institute of Physics.

Cleaves, A. (2005) *International Journal of Science Education*, 27, 471-486.

Filloy, E. & Rojano, T. (1989) *For the Learning of Mathematics*, 9(2), 19-25.

Gilbert, J. (Ed.) (2006) *Science Education in Schools*, TLRP.

Harré, R., & Gillett, G. (1995) *The Discursive Mind*, Sage.

Hoban, G. (2002) *Teacher Learning for Educational Change*, Open University Press.

HM Treasury (2004) *Science & Innovation Investment Framework 2004-2014*, HM Treasury.

Hollins, M., Murphy, P., Ponchaud, B. & Whitelegg, E. (2006) *Girls in the Physics Classroom*, Institute of Physics.

Hoyles, C., Küchemann, D., Healy, L. & Yang, M. (2005) *International Journal of Social Research Methodology*, 8, 225-238.

Keller, E. F. (1983) *A Feeling for the Organism*, W. H. Freeman.

Kyriacou C. & Goulding M. (2006) *A systematic review of strategies to raise pupils' motivational effort in Key Stage 4 Mathematics*. Report. EPPI-Centre.

Lave, J. (1988) *Cognition in Practice*, New York: Cambridge University Press.

Lord, P & Jones, M. (2006) *Pupils' Experiences and Perspectives of the National Curriculum and Assessment*, NFER.

Mendick, H. (2006) *Masculinities in Mathematics*, Open University Press.

Millar, R., Leach, J., Osborne, J. & Ratcliffe, M. (2006) *Improving Subject Teaching*, Routledge.

Murphy, P. & Whitelegg, E. (2006) *Girls in the Physics Classroom*, Institute of Physics.

Nkhoma, P. M. (2002) *Educational Studies in Mathematics*, 50, 103-113.

Noss R & Hoyles C (1996) *Windows on Mathematical Meanings*, Kluwer.

Nunes, T., Schliemann, A., & Carraher, D. (1993) *Street Mathematics and School Mathematics*, Cambridge University Press.

OECD (2006) *Evolution of Student Interest in Science and Technology Studies*, OECD.

Osborne, J., Simon, S. & Collins, S. (2003) *International Journal of Science Education*, 25, 1049-1079.

PISA (2006) *Assessing Scientific, Reading and Mathematical Literacy*, OECD.

Reiss, M. J. (2000) *Understanding Science Lessons*, Open University Press.

Reiss, M. J. (2005) In Alsop, S. (ed.), *Beyond Cartesian Dualism*, Kluwer, pp. 17-25.

Rodd, M. & Bartholomew, H. (2006) *Gender & Education*, 18, 35-50.

Rodd, M. & Brown, M. (2004) *Successful undergraduate mathematicians: a study of students in two universities*, 28th Conference of the International Group for the Psychology of Mathematics, Bergen University College.

Schreiner, C. (2006) *Exploring a ROSE-Garden, University of Oslo*.

Sfard, A. (2007). *When the rules of discourse change, but nobody tells you: Making sense of mathematics learning from a commognitive standpoint*. Journal for Learning Sciences, 16(4), 567–615.

Sfard, A., & Prusak, A. (2005). *Telling identities: In search of an analytic tool for investigating learning as a culturally shaped activity*. Educational Researcher, 34(4), 14-22.

Smithers, A. & Robinson, P. (2007) *Physics in Schools III*, Carmichael Press.

Turkle S. & Papert, S (1992) *Journal of Mathematical Behavior*, 11, 3-33.

van Hiele, P. M. (1959/2004) In T. P. Carpenter, J. A. Dossey & J. L. Koelher (eds), *Classics in Mathematics Education Research*, National Council of Teachers of Mathematics, pp. 60-67.

Walkerdine, V. (1988) *The Mastery of Reason*, Routledge.

Zohar, A. (2006) *Journal of Science Education*, 28, 1579-1599.

Methodology

Strand 1: Mapping trajectories of engagement and disenchantment

In Strand 1 we will build on existing (e.g. Hollins et al., 2006; Bradshaw, 2007; Smithers & Robinson, 2007) and on-going work by the DfES (including the Secondary National Strategy), ESRC, Ofsted and others.

Strand 1 Sample: We have established agreements to work on this strand with the DfES, Ofsted and the SSAT. We will use these and our own contacts (through the NCETM, SLCs, the Institute of Education¡¯s initial teacher education partnership schools, previous schools that have worked with us and personal contacts in various universities including ones in Northern Ireland, Scotland and Wales) to identify 200 schools across the UK that agree to work with us and who are judged by these different sources (i) to have below average (n = 50), average (n = 50) and above average (n = 100) rates of staying on post-16 in mathematics / physics (above and below averages might hold for all students or particular groups, e.g. girls, BME students); (ii) to include a substantial number (n ¡Ö 100) of schools that have participated in one or more of the many initiatives, classroom-based or otherwise, to increase participation in mathematics or physics / science. We will not attempt to obtain a random sample of schools, since too many schools decline to accept invitations to participate in research projects for that to be feasible, especially as such declinations are more likely to come from certain categories of schools. Rather, we will use targeted sampling to ensure adequate sample sizes for each of the above categories. Additionally, we will include grammar and independent schools in all three of our staying on rate categories while ensuring that approximately 85% of our sample consists of non-selective state schools.

We do not underestimate the issues involved in obtaining agreement from this number of schools to work with us but we have considerable experience of recruiting and working with large numbers of schools in this way. For example, in one longitudinal four-year ESRC-funded research project, Hoyles et al. (2005) found that in the process of recruitment of schools (where retention was critical) it was important to work with the appropriate local network leader (LEA mathematics advisers), who served to assist in the selection process, encouraged schools to participate and supported schools to remain in the project over its four years. In this project this role will be performed by LA experts alongside experts drawn from the other networks set out above (e.g. SSAT, SLCs).

Contact will be made with each of the 200 schools to identify inconsistencies in, update and enhance the preliminary data used for their selection (e.g. with regard to the nature of the mathematics and science / physics curricula at GCSE and advanced level).

Strand 1 Design: We will identify from the literature, our own knowledge of the effectiveness of different initiatives and focus groups of teachers, mathematicians and physicists occasions in the development of mathematics and physics where, in order to make any further advancement, some previously developed concepts must be reconsidered. We focus on these concepts, called core notions, as it might be at these points of disjuncture that students lose confidence and motivation. A science example is what happens to the term ¡®force¡¯ in the transition from Aristotelian to Newtonian physics; in mathematics, examples include successive extensions of the number set, e.g. the transition from unsigned to signed numbers (Sfard, in press), the introduction of symbolic algebra (Filloy & Rojano, 1989) and the transition from everyday argumentation about shapes to formal Euclidean geometry (van Hiele, 2004/1959).

We will devise items to assess (separately) understanding of and engagement with these core notions and incorporate these in a student questionnaire that will include items to assess attitudes and perceptions of mathematics and physics, along with personal data such as gender, ethnicity, parental occupations and number of books at home. We have approached the OECD with a view to incorporating aspects of the 2006 PISA questionnaire (PISA, 2006) and anticipate receiving permission to do this. We will also construct a simple school questionnaire to obtain data on type of school (11-16, 11-18, selective etc.), curricula in mathematics and science, and any interventions to promote engagement in mathematics and/or physics.

The student questionnaire will be trialled over a period of about three months with some 200 students in a total of 5 schools. Following modification, it will be administered to approximately 100 12/13 year-old (Year 8 in England & Wales; Year 9 in Northern Ireland; Secondary 1 in Scotland) and 100 14/15 year-old (Year 10 in England & Wales; Year 11 in Northern Ireland; Secondary 3 in Scotland) students from across the ability range in each of 200 schools. Employing a longitudinal design, these questionnaires will be individually identified and distributed (with supplementary questions that draw on the initial findings of Strand 2 of the work) to the same students two years later. Relevant data on individual student attainment will be gathered from each school. Most schools are likely to want paper copies of the questionnaire but we will also make it available electronically. We anticipate contacting post-16 students in a range of ways (letters via their schools/colleges, voice mail, SMS, e-mail, etc.).

Strand 1 Analysis: Assuming an 80% completion rate from the 12/13 year-olds two years later and a 60% completion rate from the 14/15 year-olds two years later this gives us sample sizes, respectively, of 16,000 and 12,000. This will enable us to map trajectories of engagement and disenchantment for diverse students, using simple descriptive statistics, and also to quantify, using a similar multi-level modelling approach to that employed by Hoyles et al. (2005), the extent to which certain constellations of factors at different levels predict post-16 participation in mathematics and/or physics.

From existing work, we envisage that schools with above average post-16 participation will have such characteristics as a high proportion of 14 year-olds with above average attainment (level 6 on KS3 mathematics / science tests in England), mathematics / science departments rated by Estyn, ETI, HMIE or Ofsted as being of above average quality, students who are predominantly of high and middle socio-economic class, male (particularly in physics) and from India / the Far East, and teachers with mathematics and physics specialisms.

Our research will seek to quantify the importance of these factors or combinations of these factors in relation to different student groups, for example for girls and for boys. We will identify ¡®outlier¡¯ schools, where the analysis indicates patterns of post-16 participation in mathematics and physics that appear not to be accounted for by the factors listed in the previous paragraph. In particular, we will look specifically for the impact on certain groups of students of a higher than average incidence of STEM enhancement (e.g. through school clubs and science and engineering ambassadors).

Strand 2: Investigating subjectivities and school culture

In Strand 2 we will work with 12 of these 200 schools in England (4 state schools in each of the three staying on rate categories) in more depth.

Strand 2 Sample: The sample will include outlier schools identified in Strand 1. As far as possible, we will choose schools in each of the cells of a matrix of high / low participation in mathematics / physics so as to be able to tease out interactions between the two subjects with regard to student attitudes and subject choices. This will help us to see the extent to which the same factors are or are not at work in mathematics and physics with regard to higher than expected post-16 participation rates.

Our focus will be on 14/15 year-olds of above average attainment in one or both of mathematics and science. In each school we will work with six students, identified from the student questionnaire responses: one girl and one boy who intend to study mathematics and/or physics post-16; one girl and one boy who are undecided; one girl and one boy who intend not to study mathematics and/or physics post-16. Each of these 72 students will be individually interviewed three times, at ages 15, 16 and 17 (when they may be in school, in college, in employment, in training or NEET), on each occasion for between 20 and 30 minutes.

Strand 2 Design: Our interviewing will draw on the approaches used by Reiss (2000), Cleaves (2005) and Mendick (2006) so as to uncover student subjectivities. We will utilise aspects of both semi-structured and narrative interviewing, allowing us to cover certain core questions with all interviewees (exploring, for example, student views of the role of parents and other significant adults, peers, teachers and out-of-school experiences on subject choice; student understandings of the nature of mathematics / physics and, as a control, English; student views of their abilities in mathematics / physics and English and their relationships to the subjects) but giving every opportunity to the interviewee to address issues not raised by the interviewer.

We will complement such data with ethnographic observations of classroom or out-of-classroom activities including activities identified from the Strand 2 interviews or the analyses in Strand 1. In each school we will observe five lessons / out-of-classroom activities (likely to include science clubs, visits, department meetings) in mathematics and five in physics. This gives us a sample of 120 lessons / out-of-classroom activities. Rather than using a fixed observation schedule we will use a more open schedule based on those factors identified in the literature (e.g. Hollins et al., 2006; Kyriacou & Goulding, 2006), in Strand 1 and from the on-going interviews in Strand 2 as being of potential significance (likely to include type of questioning by the teacher, extent of student collaboration, use of language, degree of student autonomy, use of textbooks, seating and other working arrangements).

In each of the 12 schools we will work with two teacher researchers whom we will mentor and who will gather data on school culture and student activities. We will bring all 24 teacher researchers together for an initial meeting at which we will share the conceptual basis for the project and introduce them to their role. Data will be recorded by the teacher researchers in diaries or blogs in the form of critical events that, in the teachers¡¯ view, have an impact on students¡¯ connection with subject discourses, meaning-making and identity, and that influence subject choice. The teacher researchers will be asked to identify interventions and teaching approaches that stimulate positive attitudes. An on-line forum will be set up to enable the teacher researchers to participate in discussions about research issues and reflect on the impact of interventions in their schools. Engaging collaboratively in reflective analysis has been shown to enhance professional learning (Hoban, 2002), and these teachers will have the opportunity to draw on their research experience by enrolling on appropriate CPD courses at the Institute of Education (e.g. on-line Master¡¯s modules) without being charged for this. The involvement of teachers as researchers will expand the data base and help with teacher research capacity building.

Strand 2 Analysis: Our interview technique will increase the chance of uncovering relevant factors not envisaged by us or captured in the earlier analyses and of allowing interviewees to contextualise and trace connections between factors. Students¡¯ identities will also be reconstructed from stories told by them and from their unsolicited self-referential remarks.

Essentially, interviews reveal data about interviewees¡¯ perceptions. The ethnographic element of the fieldwork will allow us to triangulate both the interview findings and the conclusions from the student questionnaires. It will be as interesting if it transpires that there is no concordance between these various datasets as if they agree perfectly; in practice, the reality is likely to lie somewhere between these extremes.

Strand 3: Documenting the reasons for HE choices

In Strand 3, Documenting the reasons for HE choices, we will work with first year undergraduates as at that stage they will have made their subject or initial career choices and we want know what factors they believe influenced these choices.

Strand 3 Sample: We have agreement to work with Oxford Brookes University, Queen Mary¡¯s College London, Manchester University and University College London. T We will recruit 50 students under the age of 21 across these four HEIs. At each HEI, students will be invited to respond to an electronic questionnaire, on the lines of Nkhoma (2002), that includes information on their backgrounds and their university entry qualifications. From these responses, we will recruit 25 students who have started first degree courses in accountancy, mathematics, engineering or physics, and 25 students who have started other degrees, yet have qualifications that would have allowed them to start accountancy, mathematics, engineering or physics courses. We are particularly interested in recruiting STEM students who have unusual profiles for the choices they have made (cf. Rodd & Brown, 2004).

Strand 3 Design: The students will be fully informed about the project and how their contribution should help us develop new knowledge about young peoples¡¯ decision-making. Working with CRAC we will develop a semi-structured, narrative-style interview schedule. The design of this schedule will be informed by the research for the design of the questionnaire in Strand 1, by early findings from Strand 2, by emerging findings from the HEFCE-funded More Maths Grads and Stimulating Physics projects, by recent unpublished work CRAC has undertaken with engineering undergraduates and their career mindsets, choices and career influences, by CRAC¡¯s own experience, by related National Institute for Careers Education and Counselling experience and by what exists in the literature. In addition, we will ensure some comparability with the Higher Education Careers Services Unit¡¯s Futuretrack by using some common questions.

Strand 3 Analysis: We aim to capture students¡¯ accounts of their affective reactions to both mathematics and physics and whether their ¡®designated identities¡¯ of mid-adolescence have adapted, or not, to participate in mathematics or physics (Rodd & Bartholomew, 2006). Our analysis of their interviews will result in ¡®narratives of choice¡¯ ¨C personalised accounts of how choices seem to have been presented to the students (by parents, by career advisers and by others) ¨C and examples of serendipitous events or critical incidents that seemed to the students to have influenced their decision-making. This will allow us to probe our Strand 1 and Strand 2 conclusions with regard to what makes for an effective intervention.