Student learning through collaborative design and teaching of STEM Foundation Mathematics: Catalyst Project[1]

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We introduce our Catalyst A Project focusing on innovation in teaching of mathematics with university students in a Foundation Studies programme. The innovation involves the inclusion of Student-Partners (SPs), former Foundation students, in design of tasks for their current peers. Tasks are designed for two topics, *Complex Numbers* and *Matrices*, using computer learning environments *Autograph* and *GeoGebra*. We study the task design process and the involvement of students, seeking to understand students' perceptions of tasks that are helpful for conceptual learning. The SPs also join us in tutorials for the current cohort. Our research is developmental in feeding back to current practice from what we learn in studying it.

Keywords: Mathematics teaching; university *Foundation* students; innovation; computer-based tasks; student-partners; developmental research.

Project aims

This Catalyst Project is being conducted by the Mathematics Education Centre (MEC), within the School of Science, at Loughborough University (LU). It focuses on the teaching of mathematics within the university's Foundation Studies programme, with the following aims:

1. To develop curriculum innovations across the School of Science and promote interdisciplinary professional practice in STEM areas.
2. To promote collaboration between staff and students that results in higher degrees of confidence, motivation and learning in mathematics and a new culture in the teaching-learning of mathematics (e.g., HEA, 2014).
3. To generate knowledge about student involvement in mathematics curriculum development for use at LU and dissemination more widely.

Building on previous research in the MEC

The project builds on findings from two earlier projects conducted by the MEC. These were the ESUM Project (Engineering Students Understanding Mathematics) and the SYMBoL Project (Second Year Mathematics Beyond Lectures). The first of these involved an innovation in the first year teaching of mathematics to engineering students, using inquiry-based questions, a computer learning environment (GeoGebra), small group activity in tutorials and a small-group assessed project. The finding on which we build in Catalyst is that the teaching team and the student cohort perceived the innovation very differently, related to culturally rooted expectations in each of the groups (Jaworski, Robinson, Matthews and Croft, 2012). In Catalyst we

[1] A HEFCE Catalyst A Project: http://www.hefce.ac.uk/lt/innovationfund/projects/

hoped to learn more about these cultural expectations and their influence on the effects of innovation in teaching.

The second project created a partnership between four second-year students and several mathematics staff in relation to two second-year modules with a history of poor student performance (Vector Spaces and Complex Variables). The student partners (interns) liaised with the lecturers of the two modules to design resources that would help future students to be more successful in these areas of mathematics. The partnership proved to be extremely fruitful for both the interns and the staff, developing good relationships through which both groups learned. This learning led to a peer-support scheme related to the two modules in the succeeding years. Volunteer student leaders from the third-year led tutorials with their second-year counterparts in the two modules, using the resources the interns had prepared. These tutorials were well attended and were associated with higher grades for attendees (Duah, Croft & Inglis, 2013; Solomon, Croft, Duah, & Lawson, 2014). In Catalyst we build on these positive outcomes in the employment of student-partners in task design.

Innovation and Inquiry

Our innovation in the Catalyst Project has two main areas of inquiry:

1. The design of computer-based tasks in *matrices* and *complex numbers* for Foundation students.
2. The involvement of students in the design of teaching and in the tutorial teaching of foundation level students.

We are working with four student-partners to design tasks using computer software *Autograph* and *GeoGebra* in the two topic areas. Tasks are for use in tutorials with Foundation students.

The Foundation Studies Programme

This one-year programme is for students who wish to study in science or engineering but do not yet have the necessary qualifications. According to its specification, the programme provides "*An opportunity to make it onto a degree course at Loughborough University"* (http://www.lboro.ac.uk/departments/foundation/). Within the programme there is a wide range of student experience in mathematics from GCSE grade C to A level grade A. We focus on a mathematics module called 'Applicable Mathematics' which prepares students to take up degree programmes in Science or Engineering. The two semesters focus on the following topics.

Semester 1: Algebra, Logarithms, Inequalities, Functions, Trigonometry, Vectors, Differentiation, Integration, Sequences

Semester 2: Polynomials, Partial Fractions, Further Calculus, Conic Sections, Vectors**, Matrices, Complex Numbers.**

Thus, we prepare for the teaching of Matrices and Complex Numbers in Semester 2.

Project Participants

The four student-partners (SPs) had been foundation students in the year prior to the project and achieved good grades in mathematics. At the start of the project they were in their first year in fields of science and engineering (from Chemistry, Physics, Mechanical Engineering and Chemical Engineering). In interviews, they gave good accounts of why they would like to be part of Catalyst, and committed themselves to

the work of the project. We hope to gain insights into student culture -- to learn from them about:

- student perspectives in doing and learning mathematics,
- the kinds of tasks that are helpful to students,
- the approaches to teaching that they value (or not),
- how they see their role(s) as learners and as partners with teaching staff.

Our expectations are that they will

- learn to use Autograph
- familiarise themselves with the two topics,
- suggest aspects of the topic with which students might need help,
- design inspiring/engaging tasks in collaboration with staff,
- join staff in teaching in tutorials.

Other participants in the project are

- A consultant who is an *Autograph* expert.
- Two Analytical Assistants (experienced PhD students) to gather and organise data and contribute to analysis.
- An Advisory Group involving colleagues from MEC, Physics, Chemistry and Electrical Engineering, plus one external member from industry.

Theoretical and Methodological Perspectives:

We engage in Developmental Research: that is research which charts development but also feeds back into the developmental process (Jaworski, 2003). We take very generally a Vygotskian socio-cultural perspective (involving concepts of mediation, tool use, activity and action – see for example Wertsch, 1991), trying to glean as much as possible about the people (interactions and perspectives) and the setting in which we work and collect data.

Our *Research Questions* at this stage of the project, related to the aims of the project, are as follows:

1. a) What can we discern about the design of computer-based tasks for the Mathematics Foundation Studies programme from the developmental activity in the Catalyst project?
   b) How do foundation students work with the designed tasks? What issues arise?
2. a) What do we learn from the student-partners about student-culture in learning mathematics from their activity in the project, from their own perspectives, and from their views on the learning and expectations of their peers?
   b) What do we learn about Foundation students' learning of mathematics with the designed tasks? What issues arise?
3. a) In what ways can we generalise from observations and issues in (1) and (2) that is of relevance for mathematics learning and teaching more broadly and its development?
   b) In what ways is what we have learned in this project relevant to the development of teaching and learning more generally in HE?

Data, which will be analysed to address these questions includes:

1. The involvement of SPs and staff in the design process as shown through recordings of project meetings, SP reflections/reports, documents (we collect/copy documents at the design meetings and from the SPs' own work).
2. The tasks, and their use as seen through observation and discussion.
3. SP reports; interviews with SPs; Survey/Interviews with Foundation students.

Analysis of particular data will be related to the research question(s) being addressed.

The Advisory Group

Our five-member advisory group has the task to advise and monitor activity. Some of the tasks involved are:

- Observation of activity and feedback.
- Evaluation of tasks.
- Interviewing of Student-Partners and Foundation students.

We hope that, in their scrutiny of this project, they will consider the use of student partners and peer teaching in science and engineering more widely and report on this within the School and University.

Project Timescale

The project started on Dec 1st 2016. By mid-January (after a 3-week Christmas break):

- Four Student-Partners were appointed (following invitation to all of the previous year's cohort to apply, and with interviews of the applicants);
- Two AAs were appointed (following an invitation to mathematics education PhD students and interviews with applicants);
- An expert consultant was recruited by invitation;
- The AG was recruited by invitation.

We had a tight timescale due to the second semester starting at the beginning of February and the teaching of our two topics due to take place just before and just after Easter (end of March and beginning of May).

We held our first project meeting (involving all participants other than the AG) on 25th January, which consisted of an introduction to *Autograph*. Our second project meeting took place on 8th February and consisted of first thoughts on our design of tasks. This was followed by ongoing work on tasks. We held our first AG meeting on 27th February, when we briefed the AG and solicited their involvement and support. At this stage this involved commenting on the tasks as they emerged. In our third project meeting on 9th March, we reviewed tasks to date.

Activity to date

As we write this text, during the Easter break, we draw breath very briefly between the teaching of the two topics. Teaching of Complex Numbers took place near the end of March. Prior to this teaching, the tasks on Complex Numbers, designed by the SPs and discussed with staff and consultant, had been finalised. One AG member reviewed and commented on the tasks before finalising. Tasks were organised for the students into a style with which students were already familiar. They had engaged previously with tasks using Autograph in connection with topics in calculus, so the software was familiar to them. They had had six lectures on Complex Numbers before the tutorials, so had had opportunity to become familiar with theory on Complex Numbers. The tutorials were audio-recorded: the teacher and one researcher carried recorders as they interacted with students. One SP attended the tutorials and also recorded conversations with the students.

In addition to this data collection in tutorials, the following data was also collected:

- Regular reflections from SPs, prompted by the AAs.

- Recording of all project meetings including the AG meeting;
- Interviews with SPs conducted by one researcher.

Data collection and organisation was done by the two AAs, sharing the work involved. Led by one researcher, the AAs have begun analysis of the tutorial data.

After the Easter break we shall conduct the second set of tutorials focusing on the Matrix tasks. These tasks have been finalised and are currently being prepared for presentation to students. What we have learned from our first presentation of tasks to students will influence the second presentation.

Developmental research is ongoing. Feedback occurs as we act, observe and collect data. We become aware of issues related to context, institution, students, tight timescale, software use, and so on. Discussion of these issues becomes part of ongoing planning and associated activity. We try to document it all. In our final section below, we sketch some of these issues as we are experiencing them. Reporting from more rigorous analysis of data will be left for future papers.

Some issues arising to date.

1. Timescale

An issue from the start was the short amount of time available for the required work. The project had to start on December 1st 2016 and end on March 31st 2018. The tasks had to be prepared for Semester 2 (February – June) of the academic year, so this could only take place in 2017. The first use of tasks had to be in Week 8 – the week of 27th March, 2017. Thus, in this (tight) timescale (10 weeks) a lot has been achieved, but the time available has limited what we have been able to do.

2. Involvement of SPs

This has been a new kind of activity for the SPs who have engaged largely very well indeed. They have shown commitment and maturity and behaved very responsibly. However, they have had conflicting demands on their time, and their university work has had to come first. This has meant they have not always been available at the times we would have liked, and it was sometimes impossible to organise a meeting when all could be present. At the crucial tutorials on March 27th, only one SP was able to be there for only one tutorial. This means that we have, so far, very little experience (or data) of/on the involvement of the SPs in 'teaching' the Foundation Students (FSs). Overall, we have not been able to spend nearly enough time with the SPs.

3. Foundation student participation in the research

The tutorials took place in Week 8, the last week before the Easter break. They were poorly attended. Students who came were invited to participate in the research, but some declined. Those who accepted were given information about the project and completed a consent form. Each student had a sheet of problems to use alongside their use of Autograph, as well as a 'normal' worksheet related to their tutorial work for the week. This amount of paper was cumbersome and contributed to making the tutorials more of a 'production' than we would have preferred.

Two of the research team were present in the tutorials. One, the regular teacher, was able to interact with students and record their responses; some students were less forthcoming with the other researcher.

An issue for the FSs is motivation to engage with these tasks and tutorials. If they do not feel the tasks contribute to their assessed work, many may decide that they do not wish to engage. This raises questions as to how we convince them that engagement is worthwhile. We are thinking further on this.

4. First set of tutorials are a pilot

Although we had not planned it as such, we have to treat the first set of tutorials as a pilot and try to learn from what we experienced. We had a good set of tasks, resulting from collaboration with the SPs. The time it took us to further prepare these tasks for the FSs was considerable. This was related to our expectations as staff on what is needed in terms of tasks for our students, and the amount of time needed for preparation of computer-based tasks. This placed considerable extra demands on the teacher for which we would like to have been better prepared.

Because we had only one SP present at one tutorial, we were not really able to judge what contribution the SPs can make to teaching the FSs. We needed to do more in preparing the SPs for this experience. However, their regular timetable demands made this difficult.

We are now planning the second set of tutorials (in Week 10),in which (we hope) we will have learned from the first set. In addition to the tutorials we plan to hold an additional session in which we invite (and pay) students (in Week 9) to test the tasks for us (there is money for this in the budget). We still have to decide whether to hold any revision tutorials in Weeks 11, 12.

And in conclusion …

It is perhaps unusual to air the kind of issues that you read above. However, we believe that developmental research requires open transparency and honesty about the conducting of the research. The sociocultural setting requires that findings in the project are embedded in the full situation and context in which the activity takes place. In future papers we will address these perspectives in more detail and report from our analytical processes.

References

Duah, F., Croft, T., & Inglis, M. (2013) Can peer assisted learning be effective in undergraduate mathematics?, *International Journal of Mathematical Education in Science and Technology*, *45* (4), 552–565.

Higher Education Academy (2014). *Framework for Partnership in learning and teaching in Higher Education.* HEA.

Jaworski, B. (2003). Research practice into/influencing mathematics teaching and learning development: towards a theoretical framework based on co-learning partnerships. *Educational Studies in Mathematics, 54* (2-3), 249-282

Jaworski, B., Robinson C., Matthews J., Croft A.C. (2012). An activity theory analysis of teaching goals versus student epistemological positions. *International Journal Technology in Mathematics Education 19* (4), 147-152.

Solomon, Y., Croft, T., Duah, D. & Lawson, D., (2014). Reshaping understandings of teaching-learning relationships in undergraduate mathematics: An activity theory analysis of the role and impact of student internships, *Learning, Culture and Social Interaction, 3*, 323-333.

Wertsch, J. V. (1991). *Voices of the mind*. Cambridge MA: Harvard University Press.