Institution:
University of Central Lancashire

Unit of Assessment: UoA10 Mathematical Sciences

Title of case study: ***Building student resilience to counteract mathematical anxiety in Benin and the UK***

Period when the underpinning research was undertaken: 2015-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s): Dr Davide Penazzi	**Role(s) (e.g. job title):** Senior Lecturer in Mathematics	**Period(s) employed by submitting HEI:** 2013-present

Period when the claimed impact occurred: 2017-2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Mathematical Anxiety is a debilitating tension and worry that besets many children, students and adults. Sufferers will try to avoid any kind of mathematical activity and choose careers where mathematical skills are not required. By developing methods that teach mathematics experientially, assisting reflection and fostering 'mathematical resilience,' Penazzi has led a change in maths teaching in Benin. This has positively affected student attainment and the perception of maths by both students and teachers. In a three-day residential course in UK Higher Education Penazzi's experiential teaching techniques increased the attainment of students by more than one-degree classification and in Benin it is changing the way mathematics is taught. As a consequence, teachers report lower levels of anxiety amongst students who now perform better, understand and engage with the subject and gain improved results.

2. Underpinning research (indicative maximum 500 words)

As an active researcher in model theory and in the topological dynamics of algebraic groups [1, 2], Penazzi enjoyed the challenge of discovering novel truths and exploring uncharted mathematical territory. Passion for mathematics shaped Penazzi's learning, but, when looking at his students, he noticed that, for most of them, their motivation did not arise from any pleasure in learning or the challenge of the mathematical problems. He identified that the majority of students saw mathematics as a passive process, mostly memorizing formulae and routines and then being able to replicate them in exams. A lack of any deeper understanding of the subject creates challenges when students tackle increasingly complex or applied mathematical problems. Many students showed signs of tension, apprehension and fear that has been identified with Mathematical Anxiety. This anxiety does not mean that students are necessarily bad at maths, rather that the thought of solving mathematical problems generates the anxiety. Teachers may also experience Mathematical Anxiety and this can affect the way that they teach the subject. However, the experience of working mathematicians is profoundly different to that of teachers or students suffering from Mathematical Anxiety. Penazzi's research investigates the causes of Mathematical Anxiety and has developed solutions that address the issue.

There has been a documented steady decline in the basic mathematical skills of students starting a STEM university degree across the world. This decline has been noted by a number of international research studies and the European Society for Engineering Education's report *Mathematics for the European Engineer* in 2002 commented that the decline was 'common in the Western world.' The effect of disengagement is felt in relatively low numbers of students worldwide choosing mathematics-heavy routes in high school and mathematics degrees in HE. Consequently, there is a lack of a STEM-knowledgeable workforce globally. The 2017 UK Government commons select committee report *Industrial Strategy: science and STEM skills,* states under section 3 'Closing the STEM skills gap': 'Nearly 40% of UK employers report difficulties recruiting staff with relevant STEM skills.'

Mathematical Anxiety does not just encompass cognitive numeracy skills, such as content knowledge and application. It is also experienced in the affective sphere, affecting our emotional capacity to apply ourselves to any given task. What is missing therefore is mathematical resilience, a combination of cognitive and affective skills that equip students with the desire to value the subject. This helps provide the tenacity to struggle with the learning required and the ability to find the resources needed to help understanding. Students with Mathematical Anxiety lack an optimistic outlook on the subject that would support creative mathematical problem solving. Penazzi's research in Benin has identified that, pedagogically, maths was very orderly, but rule-bound, with students disengaged and unable to explore problems creatively.

To address the problem of Mathematical Anxiety Penazzi collaborated with Senior Coach Jo McCready and Frontier Education outdoor course director Sharon Rosser. They redesigned an existing outdoor provision and created involving challenges that would make learning mathematics enjoyable [3]. The pleasure derived from mathematics comes from the satisfaction of successful problem solving and exploration of new ideas. Outdoor learning presented a similar positive experience and by incorporating mathematical problems into these activities, Penazzi developed a powerful tool to engage previously disengaged students. The collaboration led to the development of a theory of the blended use of experiential learning and coaching techniques to support the learning of mathematics. This approach was called Promoting Engagement in Mathematics Experientially (PEME). The course makes students experience some of the new demands of higher education, in particular, making them reflect on how they can best approach their problems. These may be difficulties in understanding, how they can organize themselves efficiently, and how small but incremental triumphs provide a sense of achievement and the self-confidence to address stubborn problems.

The three-day residential course, 'Frontier Education Mathematics', developed simple non-mathematical team activities that simulated mathematical processes. These activities developed teamwork, critical thinking, precision and communication skills. The exercises created an unencumbered experience, inspiring creative problem-solving, fortitude and the resilience required for the dedicated study of mathematics. This circumvented the ingrained perception of mathematics as a potentially worrisome memory exercise. Facilitation sessions and reflective discussions after the activities helped students move away from their past learning experiences and engage more actively with their degree studies [3].

As a shorter alternative, Penazzi developed a condensed version of the program for Welcome Weeks in HE [4] and in schools [5]. A version of the PEME approach was also developed for teachers to address Mathematical Anxiety both in themselves as learners and as educators teaching it to others. These short activities are called EMAs - Experiential Mathematical Activities. Penazzi presented and tested them in schools and developed a programme of training for teachers on how to create, deliver and facilitate these short 'EMA' sessions.

EMAs can be adapted to any school level and are based on a 'threshold concept' which opens up a new and previously inaccessible way of thinking. These short Experiential Mathematical Activities combat Mathematical Anxiety by creating memorable moments, having real-life applications or by creating identification with a student's experience.

One fundamental aspect of the whole process, which makes it unique as a mathematical intervention, is the dedicated facilitation session after the activities. This reflection helps to further motivate the students when they revisit their experience and find a personal relevance that resonates with their own interests [6].

3. References to the research (indicative maximum of six references)

[1] Gismatullin, Jakub; Penazzi, Davide and Pillay, Anand (2014) 'On compactifications and the topological dynamics of definable groups,' *Annals of Pure and Applied Logic*, 165 (2). pp. 552-562. ISSN 01680072. DOI: https://doi.org/10.1016/j.apal.2013.07.020

[2] Penazzi, Davide, Pillay, Anand and Yao, Ningyuan (2019) 'Some model theory and topological dynamics of p-adic algebraic groups,' *Fundamenta Mathematicae* 24, 191-216. DOI: 10.4064/fm707-3-2019

[3] Burrell, Andrew; McCready, Jo; Munshi, Zainab and Penazzi, Davide (2017) 'Developing an 'outdoor-inspired' indoor experiential mathematical activity,' *MSOR Connections*, 16 (1). ISSN 2051-4220. DOI: https://doi.org/10.21100/msor.v16i1.351
[4] Andrew Burrell, Jo McCready, Zainab Munshi, Davide Penazzi: 'Activity Guide: an outdoor – inspired indoor mathematics experience.' University of Central Lancashire, 2016. https://www.mathcentre.ac.uk/resources/uploaded/ucl1941-enquiry-bookletweb.pdf
[5] Fessey, Hannah; Penazzi, Davide (2017); 'A game to re-engage GCSE students to mathematics,' *Mathematics Education beyond 16: Pathways and Transitions*, https://cdn.ima.org.uk/wp/wp-content/uploads/2016/07/A-game-to-re-engage-GCSE-students-to-mathematics-Fessey-Penazzi-paper.docx
[6] Penazzi, Davide (2020) 'Creating experiential mathematical activities, *Mathematics Teaching*,' *Journal of the Association of Teachers of Mathematics*, 270, pp. 28-31.

4. Details of the impact (indicative maximum 750 words)

Penazzi has developed methods to teach mathematics experientially enabling students to become more mathematically resilient. This has led to a change in maths teaching in Benin, benefitting student attainment and improving the perception of maths. In the UK, Penazzi ran a three-day experiential residential course called Frontier Education Mathematics. It consisted of outdoor activities involving problem solving processes and the formulation of questions and strategies that are analogous to mathematical study. In the pre- and post-activity interaction, participants review and transfer their learning to the context of their maths course and their own future employment. After the course, one lecturer commented: "**There is a noticeable difference before and after the residential course"**, and that they were **"more lively."** Furthermore, **"In a workshop environment, the students can reinforce their learning when discussing their tasks, and helping each other out. For this purpose, the attained friendships and more active "class-life" is definitely beneficial."** [A]

Penazzi led a research trip to Benin in June 2018 that included four University of Central Lancashire students involved in his research and work in schools. Penazzi made contact with a local Non-Governmental Organisation (NGO) called Servime, which supports African countries and Benin in particular to help reduce skills loss through emigration. A partnership was created with Servime and four primary schools to support the engagement of pupils with mathematics [B].

In Beninese education, pupils attend the Ecole Primaire at 6 years old, equivalent to KS1 & 2, followed by 3 years in College-1, equivalent to KS3, and 3 years in College-2, equivalent to KS4, before entering University. For College-2 they choose between four strands or 'Series', of which only one (Serie C) has a strong mathematical content and leads to university courses in Mathematics, Physics or Engineering. Currently only around 5% of students choose Serie C, compared to the 20% that the Benin government identifies as needed for national development. In particular, the Government has identified the need for a more widespread and equal access to technical and mathematical-based courses. The focus is to create a critical mass of trained teachers who can deliver the specific pedagogical support required to increase student access to Serie C. The years in Primary school and College-1 are pivotal in the formation of the students' approach towards Mathematics. Addressing Mathematical Anxiety at this stage will help to equip more students with the confidence and skills needed to choose Serie C and then go on to study STEM courses at university. These activities address specific Objective 3 from the Benin Education Sector Plan Post 2015 which has the aim to provide children aged 3-15 access to a quality basic education [C].

Enhancing mathematics teaching in Benin through experiential mathematical activity

Penazzi and his students visited schools in Natitingou and neighbouring villages in the Atakora Department to form a discussion group to identify the strengths and weaknesses of Beninese teaching strategies. The teaching methods observed were extremely methodical, with students working rigidly within taught parameters without being given the personal space to explore problems. This regimented, disciplinary approach was discovered to be a cause of disengagement with Mathematics [J]. Teachers in Benin, like their counterparts in the UK, also

reported experiencing Mathematical Anxiety and this was highlighted in their feedback [E1]. **"A lot of teachers also didn't like mathematics, so we had a preconceived idea, mathematics is hard, it's hard, kids don't work when we didn't know how to teach [mathematics]"** Leon Mpo, Principal, EPP SOS Enfants [E2].

Penazzi and Servime agreed a plan with the local Beninese authorities [D], for a year-long pilot project with four primary schools in different settings which began in 2019. During the pilot study Penazzi trained 20 primary teachers from the four schools, which served approximately 280 pupils, on delivering Experiential Mathematical Activities [I]. A resource hub was created, operated by Servime, where teachers met and co-created six Experiential Mathematical Activities tailored to the Beninese curriculum. These new teaching materials were then delivered in all four schools.

The feedback from teachers was very positive, highlighting a general increase in their confidence in teaching mathematics: **"I used to have difficulty explaining certain mathematical concepts, but with the experiential mathematics it is easier to approach the topics"** [E1] **"With the course given by Davide Penazzi I understood that I can go via simple games to then get to satisfying results and this [made me overcome] the mathematical anxiety"** [E1].

Teachers made changes in how they presented their material, using Penazzi's strategy to teach the concepts of mathematics [E2]. **"…we have understood the importance of bringing the students to apply to reality the formulas they learn"** [E4]. Consequently**, "experiential mathematics have changed the pupils' attitudes towards maths"** and **"They are drawn towards mathematics much more because they have found an interest in it"** [E1]. A teaching pathway was formed starting from the outdoor applied, experiential mathematics and ending with the abstraction of manipulating figures and numbers in the classroom: **"The training in the methods has made my teaching easier. This training has enabled me to go from concrete to abstract mathematical ideas."** The impact of the training was to change their pupils' attitudes towards maths. **"They like the sessions much more and they are thriving."** Significantly, teachers reported better scores: **"experiential maths activities have had a significant effect on the pupils' results." "The students' results have really improved."** Teaching is easier too: **"teaching is much easier now due to the experiences we're able to give in order to pass on the knowledge"** [E1].

These projects are addressing Benin National Specific objective 3, and thus UN Sustainable Development Goal 4: 'Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.' Furthermore, with an increased number of students in STEM subjects, they are addressing Goals 8 'sustainable economic growth' and Goal 9, 'sustainable industrialization and [the fostering of] innovation'. Kevidjo Idoho, Head of the Natitingou-Toucountouna Teaching region and representative coordinator of the Ministry of Maternal and Primary Education said: **"…above all the impact is to bring a little more to the clarification of the teachings of mathematics, to the learning of mathematics by our learners and […] I think it is a good thing that children can learn mathematics more easily. The fear they have about teaching, the learning of mathematics, is dispelled by the approaches you implement."** [F]

Experiential Mathematical Activities in the UK

The first application of the project in the UK was the development of the three-day residential course to support transition to HE Mathematics, called Frontier Education Mathematics. This course has run with the first year BSc Mathematics and MMath at University of Central Lancashire since 2016. The positive effects of this intervention have been studied across four years. Students who attended the Frontier Education course have gained a 14 grade higher average percentage at the end of their first year compared to students who did not attend the course [K].

Penazzi has developed and delivered experiential learning activities in UK schools, along with CPD sessions for 20 primary and secondary school teachers. All attending teachers reported that they found the training useful. Thematic analysis shows that they will start implementing Experiential Mathematical Activities (EMAs) in their practice. The teachers stated they would use the problem-solving activities and games to elicit greater interest in maths. They also comment on changing their delivery method, embedding models that will engage with the affective sphere of the students: **"[The] comfort zone model will be in my mind when thinking about more able [students]"** says one. **"[I will spend] more time on anxiety in maths and how it can be addressed"**, says another. They will also share their knowledge with their colleagues to create good practice: **"[I will] encourage others in my school regarding [the] 'learning pit' and growth mind set."** Whilst another colleague comments that they will**: "Develop support staff approaches in school".** [H]

The effects of Covid-19

The original plan involved a visit to the four schools in Benin in May 2020 to obtain further evidence. Due to travel restrictions, it was not possible to make that visit. Some of the evidence was obtained remotely but several items of evidence collection were not possible. We were unable to meet with pupil focus groups to hear about the effects of the pilot project on their perceptions and their engagement with mathematics. Similarly, we were unable to meet with teacher's focus groups to discuss the effect of the pilot project on their perception of mathematics. We also wanted to create a working group to share experiences of delivering the developed activities and writing activities for the production of a booklet. Furthermore, we were going to meet with governmental bodies with the aim of securing a continuation of the project. Some interviews have been done but plans for further work have been paused for a year awaiting the pandemic to subside.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] Lecturer comments from the Frontier Education Maths evaluation questionnaire.
[B] Contracts with Schools and Servime to use Penazzi's methods: Tchakontè, Kouaba, Natitingou and SOS. (In French)
[C] *Benin Education Sector Plan Post 2015* (Plan Sectoriel De L'Education Post 2015) Specific Objective 3, p. 88. (In French)
[D] Signed Letter Kevidjo Adoho
[E] Feedback and evaluations from teachers and school administrators
- [E1] Feedback from Benin teachers' questionnaire translated into English.
- [E2] Interview between Jean-Baptiste, Director of Servime with school director of EPP SOS Enfants M'po Leon.
- [E3] Translated transcription of audio interview with school director of EPP Kouaba
- [E4] Translated transcription of audio interview with school director of EPP Tchakonte
- [E5] Evaluations from primary schools in Natitingou, Benin. Schools: EPP SOS, EPP Centre, EPP Kouaba, EPP Tchakonte. (In French)

[F] Translated transcription of filmed interview between Kevidjo Adoho, Chef Régional Pédagogique (Head of the school district of Natitingou-Toucountouna) and the Executive Director of the NGO Servime.
[G] Activity Guide: an outdoor – inspired indoor mathematics experience.
[H] Feedback from training session Westlake.
[I] Attendee list of teachers five training workshops in Benin.
[J] Summary of research team focus group visiting Benin.
[K] Results from first-year maths course comparing attendees and non-attendees on the 3-day Frontier Education Maths (FrEd) experiential course.