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USING ICT AND DIALOGIC TEACHING: IMPACT ON MATHEMATICAL RESILIENCE AND ATTAINMENT IN ALGEBRA OF A KENYAN SCHOOL YEAR GROUP

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Abstract

This paper is set in the context of a whole year group learning early secondary algebra using ICT in Kenya. It argues that studies about impact of ICT would benefit from paying explicit attention to the support offered by collaborative interaction of elements (pupils, teachers, language and computers) in lessons, that is, the affective dimension of pupils' mathematical learning.

In this paper, we explore the changes in learning mathematics experienced by students given an extended course using *Grid Algebra* [1]. Following Luckin et al [2], we explore the use of ICT combined with a fundamental shift in pedagogy, a shift that transforms teaching and learning by focusing on the learning experience. We examine the effect of introducing a technological tool combined with dialogic teaching upon a year group: on pupils' interest in algebra, their involvement and engagement in mathematical learning, their conceptual understanding and their attainment.

The study employs a mixed-method strategy, and data include: written work, observations, interviews and pupil questionnaires. We examine the impact on a year group, showing ways in which understanding was improved and the experience was positive for the learners. We use the construct of 'mathematical resilience' [3], a description of what is required to promote effective learning of mathematics, to analyse why this example of ICT use was so effective. The paper concludes that appropriate use of computer software can have a significant impact on effort and attainment. Additionally, emphasising affective aspects which reinforce ICT use in mathematics instruction can create an enabling environment for active pupil learning.

Keywords: *ICT-enhanced mathematics education, dialogic teaching, mathematical resilience, learning algebra*

1 INTRODUCTION

In a previous paper [4], we reported on a pilot study using *Grid Algebra* [1] with Kenyan lower secondary students. This intervention used 'dialogic teaching' [5], and the software *Grid Algebra* [1] as catalysts, within a supportive classroom culture, for pupil articulation of mathematical ideas in social interactions. In this paper, we present some results from a larger study. Research on using computers in mathematics education has largely focused on cognition. In contrast, McLeod [6] argued for integrating cognitive and affective dimensions in mathematical learning. Furthermore, Elder [7] explained that, according to neuroscience, powerful and positive emotional responses triggered by learning experiences can become part of the learners' most enduring memories. We argue that the affective dimension of pupils' mathematical learning is critically important and has not been emphasised enough in previous studies about impact of ICT. The affective dimension covers pupils' values, beliefs, attitudes and emotions. We use the construct 'mathematical resilience' [3] to discuss the affective aspects of the study.

In order to encourage more pupils developing resilient approach to learning in mathematics classrooms, Lee and Johnston-Wilder [8] listed as necessary:

- more pupil talk, less teacher talk, and the development of mathematical language;
- more expectation of effort, and growth mindset;
- provision of challenging and hard work;
- collaborative learning, working in groups and supporting each other.

They discuss the need explicitly to increase pupil agency and inclusion, in terms of both value and accessibility. These are all aspects of this study – in our view this is why the intervention was so very successful.

1.1 Research Context

This study examined the effect of intervening in a Kenyan classroom 'subculture', mediating learners' ICT use to address problematic pupil interest in algebra and engagement in mathematics. In particular, we looked at pupils' interest in algebra, their involvement and engagement in mathematical learning their mathematical resilience and their attainment.

Despite being central to the secondary mathematics curriculum, algebra is a topic many pupils disengage with and regard as 'difficult' ([9], [10], [11]). Failure to progress in algebra can have a negative impact on many pupils' motivation towards learning mathematics, and can lead them to feeling generally inadequate in mathematics ([12], [13]).

Large class size, on average 50 pupils, is a fact of life in Kenya. Teachers are pressured to cover all the content prescribed in national subject curricula. Additionally, they are expected to prepare candidates for national examinations amid typical teaching workloads of about 35 lessons per week. The circumstances have led many teachers to believe that a teacher-directed approach is necessary to cover large amounts of text-book driven content. Kanja et al [14] described how Kenyan pupils repeatedly practise problems before sitting examinations. They described teachers talking to pupils incessantly instead of allowing time for pupil reasoning and thinking. Mathematical content is presented to pupils in simplified, often decontextualized and isolated chunks that encourage memorisation of rules rather than development of higher-order thinking and problem- solving skills.

Arising out of concern in Kenya about pupils' lack of interest, participation and engagement in schools, the Kenyan Ministry of Education, Science and Technology a project titled Strengthening Mathematics and Science in Secondary School Education (SMASSE), targeting all practising subject teachers (Kanja et al, 2001). The principles adopted were: Activities, Student-centred teaching, Experiments, Improvisation-Plan, Do, See, Improve (ASEI-PDSI). Increased pupil-centred teaching was aimed at enhancing student engagement in the classrooms. However, teachers were worried that implementing pupil-centred pedagogy would slow coverage of syllabi in preparation for examinations; consequently Kenyan teachers found themselves reverting to 'usual' practice. We argue that failure in the SMASSE initiative to give direct attention to pupils' perspectives was a serious flaw.

Subsequently, the Kenyan Ministry, through the Centre for Mathematics, Science and Technology Education in Africa [15], launched an initiative to integrate ICT into education and training. This initiative recognised a gap between desired pupil-centred strategies, intended to enhance pupil participation and develop scientific minds, and the prevalent pedagogy many teachers employ. CEMASTEA proposed that embracing the critical principles in the ASEI-PDSI approach would make Science and Mathematics less theoretical, more practical, therefore more interesting, accessible and relevant to pupils. CEMASTEA acknowledged pupils as active agents and constructors of knowledge [16] in classroom contexts. This study developed CEMASTEA's plans by collating participants' perspectives about pupils learning algebra in ICT-enhanced mathematics lessons, with the intention to give greater voice to pupils.

1.2 Literature and Rationale

Nardi and Steward [17] distinguished 'quiet' disaffection, characterised by low engagement in learning, from 'visible' disaffection, seen as disruptive behaviour and negative experiences of schooling. We argue that the contribution of affect in secondary pupils' mathematical knowledge construction has not been discussed enough in studies about impact of ICT, and we seek to engender positive affect explicitly. The literature about positive 'affect' in mathematics education is perhaps best summarised by Johnston-Wilder and Lee's work on mathematical resilience [3].

We view schooling as a social experience in which learning is socially-constructed [18]. We consider the purpose of education as inspiring children's thinking and developing transferrable problem-solving skills [19], and not the transmission of knowledge. We view teaching as a means by which human values are experienced, shared and developed. We view teachers as facilitating pupils' learning by manipulating the content and conditions: the social process. Whereas the teacher may be largely responsible for pupils' social experiences, learning is a private process that takes place in the classroom. Pupils are responsible for their learning and the effort they put into this [20].

Effective learners exercise agency, which Bandura [21] defined as human capacity to control one's thought processes, motivation and effort. Research suggests that many pupils do not necessarily 'learn' what they are taught in classrooms [22]. Many pupils fail to understand content through limitations on their 'agency' [23]. In order to address problematic participation in mathematics lessons, acknowledgement is needed that learners may struggle with merging diverse views about what learning behaviours are desirable. Norris and Walker [24] recognised that cognition and affect in mathematics cannot always be reconciled by learners. In this study, we offered restructuring support for social, cultural, and linguistic processes in lessons. This restructuring included use of Bruner's three modes of representation for effective learning: enactive (actions-based); iconic (visually-stored images or 'mental' pictures); and symbolic (language-based in words and symbols) [16]. These three modes are supported by the *Grid Algebra* software [1]. We also sought to promote pupil 'talk' [5] using *Grid Algebra*-based collaborative learning activity to enhance formative feedback. The literature suggests that it is possible to use both dialogic teaching and ICT to promote 'Deep Learning' [25] that is connected and well understood. In this study we sought to interweave dialogic teaching into the pupils' experience of the *Grid Algebra* tasks.

Hewitt [1] reported pupils working with *Grid Algebra* demonstrating the capacity to learn 'difficult' algebraic concepts ahead of their chronological age. We planned to demonstrate that pupils in Kenya could do the same.

2 METHODOLOGY

The study employed a mixed-method strategy including: written work, observations, interviews and pupil questionnaires. Participants were 270 female pupils, aged on average 14 years (actual 14.22, ranging from 12 to 16 years) learned in five mixed-ability classes, each of between 53 and 56 pupils. The pupils were in Form 1 of a girls-only, state-run, fee-paying, boarding school in Nairobi, Kenya. According to Hernandez-Martinez and Williams [26], all pupils in transition need sensitive induction to develop emotional intelligence and social capital to negotiate secondary school successfully. I regarded the Form 1 cohort as 'pupils in transition' since they had only three-months experience at secondary level, with majority being first-time boarders. The research was conceived as an intervention study with a whole cohort. Dane [27] highlighted researchers' obligation to offer the 'new treatment' to participants in the control group.

The inquiry was fundamentally naturalistic. Mercer [28] deemed sociocultural theory of learning as better suited to 'naturalistic' methodology. Naturalistic study involves studying phenomena in the natural setting of activity [24]. The researcher directly experiencies people *in situ* and stays with them in some role acceptable to those being studied [24]. Effective research implementation entailed the first author becoming embedded in classrooms, assuming the role of 'teacher-facilitator'.

Introduction of computer-based collaborative activities to a school with a predominantly textbook-based ethos served to encourage more pupil 'talk' and less teacher 'talk'. Luckin et al [2] argued that content and pedagogy should drive technology use. Alexander [5] associated the concept of 'dialogic teaching' to 'assessment for learning', as advanced by Black et al [29]. The participant classes revisited complex algebraic concepts they had previously encountered at a simplified level with gradually increasing difficulty [16]. The activities allowed pupils to solve problems by themselves. Pupils were required to demonstrate their ability to link algebraic ideas appearing in multiple representations while exploring with *Grid Algebra*. A respectful defence of argument when challenged was expected of pupils. Emphasis was on turn-taking as each contributor articulated their thinking to facilitate negotiation of shared understanding [30].

3 RESULTS

The study found significant increases in pupil engagement and interaction, and enhanced pupils' learning about algebra, across a year group. One of the older pupils said: "This has really made me do more maths than I have ever had to do in class!"

We present five themes that emerged from the pupil data: changed learning environment; learner agency; changed motivation; accessible learning; enjoyment. We end the section with a description of the results in relation to attainment in which we include some teacher data and some performance data.

3.1 Changed learning environment

Several pupils described valuing the change in the learning conditions. Emphasis was placed on increased opportunities for discussion, with peers and/or the teacher. Pupils who rarely spoke in non-ICT lessons were engrossed in ICT-enhanced discussions: for example, one said she ‘got a chance to ... learn more while interacting with classmates around the computer.’ Another contrasted the ICT lessons with her usual experience: ‘In class you don’t get the chance to discuss freely and say what you don’t understand but in the lab you can pour out your views/issues to the teacher, others in the group.’

The pupils also expressed that they were learning new skills that they valued. 42% (114) of pupils attached importance to their acquisition of a variety of new ‘skills’; one pupils commented: ‘Aside from learning how to do algebra with ICT, I was also learning some computer skills, having not used it before…so *Grid Algebra* gave me enthusiasm to do maths even more.’ Another pupil said ‘Because I had never used a computer before, I get this chance to know some skills on operating the computer. It has given me another way of learning.’

Organisation of ICT-enhanced sessions was designed to encourage the development of other skills including externalising thoughts. Pupils were required to communicate mathematically whilst listening and speaking in turns in small-group working format. Some commented that they appreciated the group work; for example: ‘you can do it practically as a group helping each other as you learn more.’ Another pupil said: ‘algebra was my weakness, I managed to expand my knowledge since it may be hard to understand a teacher. Working in groups I learn more from the others.’ These pupils appeared to feel safe when given the opportunity to share with, and learn from, their peers.

The clear expectations that governed ICT-enhanced sessions required each pupil to talk through their reasoning to the group as they negotiated their solutions. All pupils took turns to listen and speak, this was a challenge that every pupil appeared to relish rather than back down from. The format of ICT-enhanced sessions was regarded as useful in facilitating equal opportunities to the resources available. Many pupils valued the increased opportunity for what one described as ‘one-on-one talk with the teacher who deals with each of us at a time.’

Others described learning activities as ‘practical’; they learnt more by ‘doing’. For example, one said: ‘It helps us understand more fast (sic) since we do it practically. Before we learnt in class where most people didn’t understand but *Grid Algebra* is easy to understand.’ Another pupil expressed appreciation of being active: ‘because the *Grid Algebra* helps you to work practically and helps you to be active unlike in just oral which we do not understand or is even boring.' For another, doing algebra practically had the effect of ‘increasing the rate of my understanding the topic.’

In summary, ICT enhancing opportunities for active learner participation in mathematical activities activity was valued by the pupils, they expressed feeling willing and able to experiment and they expressed appreciation of algebra becoming more ‘practical’ and they expressed appreciation of their peers in a learning community.

3.2 Learner agency

Many pupils indicated an awareness of the role of the computer in enabling them to take control of their own learning and to become more active learners. As one pupil put it: ‘I prefer to learn algebra through *Grid Algebra*. It also involves my participation as a student.’ A second pupil reflected on the experience using *Grid Algebra* in comparison with their previous experiences in traditional lessons: ‘We are used to teachers in class every day and writing. It is good to explore technology. It is easier for me when I master the concepts used in the computer then I apply them on paper. It opens up the mind.’ Some pupils appreciated that the ICT activities made them ‘find solutions for myself.’

Many other pupils apparently welcomed increased opportunities for agency in classroom dialogues around learning and involvement. These statements pointed to pupils’ valuing of emphasis on articulation, variety and group discussions as learners negotiated their mathematical understandings.

It is arguable that the teacher control and relative lack of learner agency, which these pupils usually experienced, engendered feelings of frustration, lack of understanding or even dislike for learning mathematics. Pupils valued trialling and re-trialling to satisfy curiosity and test predictions as they explored and experimented on computers.

Placing the ICT tool in pupils’ hands appears to have facilitated individual construction of mathematical connections; and hence ‘deep learning’. As one pupil reported: ‘I like the topic because I enjoy it and also I can understand what I am taught. Before *Grid Algebra* was introduced, I passed but I didn't know what I was doing since I practised the spoon-feeding method from teachers.'

Many pupils' responses depicted some form of 'anxiety' with the focus on procedures rather than understanding in their usual textbook-based and teacher-directed instructional practice. In the study, pupils were encouraged to pause and think about the questions and feedback whilst discussing with each other. The pupils considered their peers' actions and listened to contributions; at times they were observed to squeal with delight at the interactivity.

Visual imagery provided by the software feedback was explicitly mentioned as supportive by 31 pupils, as a new way to be agentic in learning mathematics. One pupil described this as 'another way of learning. It has made me form a mental picture when calculating algebraic expressions, e.g. when I remember how the arrows move in the computer.' Another appreciated that this imagery and the newly found agency would help them in exams: 'I recall the *Grid Algebra* lessons that were so scintillating and interesting. The layout is so real and unforgettable thus sticks in my mind, so I imagine a grid in my exam. It helps a lot.'

These responses illustrate the pupils' ability to respond: their learner agency. They valued making and seeing connections for themselves rather than being told facts in lessons by their teachers.

3.3 Changed motivation and engagement

This theme reflects the change in motivation to learning mathematics that the pupils associated with their use of *Grid Algebra* in mathematics lessons. Some pupils considered their non-ICT mathematics lessons in regular classrooms 'boring'; many described being quite disengaged with learning, a common report by their teachers. A pupil described being 'encouraged … that maths is enjoyable and can be worked even on computers, and also makes me attentive in class since I can't doze off yet there is some fun program in front of me.'

Some positive emotions (curiosity, enthusiasm, and interest shown in activity) are considered an indication of pupils' high engagement with their learning. The ICT-enhanced activity seemed to engender raised levels of engagement and concentration in learning.

Every group was required to select software-generated tasks at lower difficulty levels and gradually work their way to higher levels. The majority of the pupils complied with advice to build self-confidence; they worked, tentatively at first, in animated discussions, then with increasing concentration as they received, reflected on and responded to feedback. One pupil said: 'It is more fun and easier to understand. It has improved my concentration level a great deal.' Another described herself as 'alert every time a question is runned (sic) on the computer.'

Teacher T4 described many pupils' evident positive disposition to learning: 'I have never seen these pupils so absorbed in the work they are doing like they were today! The fact that the *Grid Algebra* was marking as the pupils worked and even giving them words of encouragement such as "Excellent!" was really giving the pupils the impetus to do more and more work! That was great! It has ensured good classroom management. I have especially liked the way the software encouraged, motivated them to try more work.'

A marked change in pupils' attitude to learning was attributed to the new learning resource. One pupil described this as: 'In the past, I never used to get algebra so I had a negative attitude towards it but it changed when I started doing *Grid Algebra* and I understood algebra more.' Others highlighted the enjoyment: 'It makes mathematics fun thus helps to develop a positive attitude towards mathematics.' For some, the enjoyment was clearly associated with being able to succeed: the software 'made me see maths as easy and enjoyable.'

Some pupils reported shifting relations to mathematics as a subject and algebra as a topic due to intrinsic values. The pupils signalled changes in their identity as 'mathematicians'. As one pupil said: 'It's because it makes you feel assured of yourself and believe you can do algebra questions given confidently.' Another pupil vividly described their increased understanding: 'It opens up minds to show that there is always a way out of what seems to be difficult questions.' Some pupils felt more interested and :encouraged 'to learn more and more about maths.'

The pupils' increased motivation to learn algebra was associated with the overall contribution of ICT-enhanced activity. This led to the raised levels of interest, self-concept, and changed attitudes to learning. Pupils showed increased confidence and competence in their ability as mathematical learners. Introduction of *Grid Algebra* was reported by regular teachers to have raised pupil interest in their learning in other non-ICT mathematics lessons.

Teachers' remarks showed awareness that their pupils were able to apply what they learned in ICT-enhanced sessions. Teacher T3 attributed the difference to the class' interaction with *Grid Algebra* defining the pupils' learning. T3 said: You have removed us from a stupor! What came out was, so mathematics can also be this interesting!

3.4 Accessible learning

This theme focuses on what Stage Three pupils had to say about ICT tool use affecting their access to learning algebra. Pupils described understanding 'more', or 'better' than on their previous encounters. By the end of the study, 83 pupils felt the topic was 'simpler' and 'easier'. The pupils' sense of 'ease' of understanding algebra seems to have been attributed to the idea of associating expressions with 'journeys' around a grid. One of the pupils who found this helpful said: 'It has helped me especially the work concerning the Inverse Journeys. On my part, it changed my perspective on that topic and showed me ways on how to go about certain equations and now I can do the algebraic equations with utmost ease.'

One teacher noted their pupils' developing 'awareness' of underlying structures, and the 'add-on' value of dynamic visual imagery to pupils' accessing algebra: 'They are very much comfortable with the concepts "expanding" and "factorizing". I like the way it was presented in the software, showing the two different routes of arriving at an expression; that one really helped them.' One pupil commented upon this, saying: 'It made learning more understandable like now I am using Inverse Journeys in topics I was not really understanding like Linear Equations.'

Defining 'transfer' as the application of knowledge learned in one situation to another, the pupils reported applying skills learnt in the computer learning environment to pen-and-paper work both in class exercises and tests. Nineteen pupils made explicit reference to the notion of 'transfer' of learning: as one pupil expressed it: 'I have understood algebra and it has become easy for me to apply even when it comes in a written test.' Another pupil referred explicitly to transfer as: 'It made it much easier for me to do algebra on paper... I now apply what I learnt on the computer in solving linear equations and even simultaneous equations.'

Several pupils also reported that the new learning medium effected a change in execution of tasks in terms of the amount of writing required. This allowed pupils to concentrate more on learning and understanding algebra. For example, one said: 'It has really helped me understand algebra more and have an interest in it. It made everything seem easier due to the less or no calculations, just understanding.' Another pupil could 'use my brain in most of the calculations instead of paper and pen.'

Pupils described valuing the activities for saving time spent on writing work. This allowed them to concentrate on solving the mathematical puzzles on the screens. Sixty-six pupils stated that ICT-enhanced learning experiences enhanced their mental arithmetic skills, making them think 'more' or 'faster'. One expressed this as: 'I got to discover an easier way of inverse journey for example and it helped in saving time while calculating. It gave you time to think mentally without putting it down on paper.' Another said simply: 'It made me think in a faster way than I did.'

The pupils appeared to acknowledge the software's role in enabling them to apply themselves mentally as they handled learning tasks. The increased mental activity may have contributed to 80 pupils feeling more competent and confident in mathematics and another 34 pupils claimed to have made progress in mathematics.

In summary, many pupils recognized and valued that their using *Grid Algebra* facilitated more access to algebraic conceptual understanding. The majority underlined the requirement to apply themselves mentally in ICT-enhanced learning. Several pupils saw the change in execution of tasks as 'less calculation, just understanding'. Pupils welcomed the increased connectivity within mathematics: this may have contributed to their progress in attainment in algebra and generally in mathematics.

3.5 Enjoyment

A comment by one pupil epitomizes this theme: 'It has made me discover that maths is fun when you understand what you are doing.'

This view exemplified learning becoming ‘pleasurable’. This relates to the emotional dimension of pupils in classrooms; it is often overlooked that the pupils’ emotional state may affect the quality of mathematical learning. Using computers can allow pupils to explore ideas, exercise responsibility for their reasoning, hence facilitate enhanced understanding in the changed classroom environment and generate enjoyment of their learning. The majority (67%) of the pupils (181) reported ‘enjoying’ the change in their learning due to the presence of ICT in the mathematics lessons, and many expressed this clearly in interviews.

‘*Grid Algebra* is easier to understand than oral hearing. It makes you enjoy maths and you want to do more. It has made me quicker in thinking. It has made me love mathematics more and enjoy the lessons more.’

‘It’s enjoyable and enables one to understand algebra easily. It has made learning algebra easier and more enjoyable.’

For other pupils, their ‘fun’ seemed to be due to their increased understanding of algebra.

‘I never knew how to carry out algebraic expressions. Now I really enjoy calculating.’

‘It makes a topic that felt so difficult, understandable. It made me enjoy algebra while doing it.’

‘I got to understand a huge bit of algebra that was giving me a problem. This includes how to simplify, writing expressions and especially the use of signs as I was never able to tackle questions with positive and negative numbers. It has made me feel that mathematics is easier and even more fun as you learn more.’

Most pupils were clearly aware of ‘understanding more’ of algebra and many attributed their ‘enjoying’ to increased connectivity of algebraic concepts.

A sense of ‘learning while playing’ evoked in ICT-enhanced sessions was alluded to by one pupil: ‘For a person like me, I had a lot of problems with algebra but now I have just found it easy and exciting because it is all about playing with numbers.’

All pupils were highly absorbed; some showed positive emotions and concentration on tasks. When sessions ended, many pupils were reluctant to leave the room: pupils asked to be allowed to continue with the activity, as one said whilst dancing: ‘I love it! It is quite addictive; hard to let go.’

Whilst most pupils seemed very absorbed in solving *Grid Algebra*-based tasks, some inquired about acquiring the software for personal use: ‘It would be great to have it at home instead of just having computer games! I can play but at the same time I’ll revise my work and build confidence in maths even as I relax.’

What emerged clearly was that pupils appeared to develop a sense of ‘love’ and ‘enjoyment’ in their learning during ICT-enhanced mathematics lessons that was not present before the intervention. Some powerful emotions and effect on pupils’ concentration were evident during one particular task, which was timed and produced increased chatter from pupils in all the five classes; observed norms of classroom protocol and social inhibition fell away whilst pupils worked with great excitement in battling to ‘beat the clock’. So great was the noise generated in learning activity that several members of senior management team rushed to the laboratory only to find pupils engrossed in their learning, totally oblivious of attracting undue attention. Every pupil remained very much focused on brainstorming in their small groups the possible movements to make across the grid. Pupils were seen making physical actions as they spoke, and trying out different ways to create prescribed expressions within time limits imposed by the software. The pupils stated that although ‘fun’, the software-generated tasks were in no way simple, but often challenging.

In summary, many pupils found that using *Grid Algebra* software on computers was associated with increased enjoyment of learning maths, conceptual understanding and connectivity. The task of distinguishing specific factors that engendered pupils’ enjoyment was not easy. It is possible that the pupils’ developing belief that computers make learning more ‘enjoyable’ may have been responsible for increased accessibility of ‘difficult’ algebra.

3.6 Impact on attainment

Measurement of impact of *Grid Algebra*’s use on overall pupil attainment in mathematics was beyond the scope of the study. Nevertheless, both teachers and pupils drew attention to pupils’ progress in three examinations taken in the course of school term. These examinations were set at departmental level and marked by respective subject teachers.

'Surprising' feedback revealed pupils' handling of questions. Stage Three pupils demonstrated firmer grasp of algebraic concepts compared with previous years. Mathematics teachers attributed this change to pupils' engagement with *Grid Algebra*. Their reports amplified a comparison of two cohorts taught by the same teacher. Teacher T3 observed that, although the Form 1 pupils of 2010 were a considerably more 'able' cohort (based on their end-of-primary school scores) compared to the Form 1 cohort in 2012, the latter handled 'difficult' algebraic concepts better. The mathematics attainment for these two cohorts is as shown in Figure.

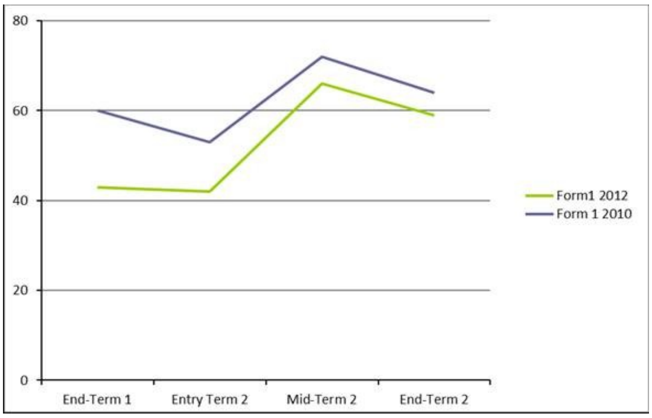

Figure: Performance of Form 1 2010 and Form 1 2012 (mathematics-with-ICT) in examinations

These results indicate that the 2012 cohort registered higher improvement in mathematics than the 2010 cohort without ICT-enhanced collaborative learning over the same academic period. Their teacher remarked on the notable differences in conceptual understanding.

'When we tell them "$a(c + d) – b(c + d)$" ... they can see $c + d$ ...they are able to factorise, because it is in both terms. They know terms which I have to teach the Form Three now since it seems they have not gotten the concept. I am very grateful because the (Form 1s) have gotten it.'

In summary, the comparison data helped establish just how much additional progress Form 1 had made over expectations. The results seemed to corroborate participants' attributing increased pupil attainment in mathematics to the changes introduced in the learning context. Albeit pleasing, impact of learning gains revealed in the mathematics examinations was incidental to my overall research aim: transformative learning processes.

3.7 Summary

In this paper, we have used use pupil voice to describe a transformation of pupils learning algebra at secondary school with emphasis on collaboration, articulation, agency, accessibility and variety mediating the use of an ICT tool. Using *Grid Algebra* led to many pupils' engagement, enjoyment, new confidence, and eagerness to participate in mathematics. It also led to noticeable increases in attainment and observable attainment-enhancing behaviours in other lessons.

4 DISCUSSION

Some studies report no impact of ICT on learning and attainment. Others report significant impact. We started this paper by claiming that one of the reasons for this was the need to consider the way in which ICT is used in terms of the affective domain. Johnston-Wilder and Lee have described the pragmatic construct 'mathematical resilience' in order to support the development of approaches to teaching and learning that incorporate the affective domain [3].

We have developed mathematical resilience in the learners through: opportunities for increased pupil talk about the mathematics; facilitating pupil agency to allow increased effort; provision of challenge; expectation that pupils should collaborate and support one another; and inclusion of a wider variety of learners through the use of Bruner's enactive and iconic stages as part of learning symbolic algebra [3].

We planned for disaffected pupils to become confident and competent learners of algebra. Change hinges upon whether ICT use is more aligned to teacher hegemony and transmission of knowledge than supportive of pupil-centred approaches which recognise learners construct their own knowledge [16]. Increased incidence of pupil ‘talk’ restricted teachers to supportive roles in the change, thus reinforcing affective aspects of cognition and instruction in mathematics. From an ‘agentic’ perspective [21], many learners seemed to feel safe to realign conceptual algebraic knowledge. Formative feedback’ [29] in learning contexts illuminated ICT’s transformative potential.

Pupils welcomed the increased connectivity within mathematics: this may have contributed to their progress in attainment in algebra and generally in mathematics.

5 CONCLUSIONS

In this paper, we have shown how we were able to improve pupils’ experiences of learning school algebra. By building upon existing knowledge of strategies that contribute to pupils developing mathematical resilience, we have shown that appropriate use of ICT, combined with a changed pedagogy that emphasised dialogic teaching, can improve accessibility, affective experience and attainment in a topic that is widely perceived as inaccessible and ‘boring’.

REFERENCES

[1] Hewitt, D. (2009). 'The role of attention in the learning of formal algebraic notation: the case of a mixed ability Year 5 using the software *Grid Algebra*', in M. Joubert (Ed.), Proceedings of the British Society for Research into Learning Mathematics, Vol. 29(3), pp. 43-48.

[2] Luckin, R., Bligh, B., Manches, A., Ainsworth, S., Crook, C., Noss, R. (2012). Decoding Learning: The Proof, Promise and Potential of Digital Education, Nesta, November 2012, www.nesta.org.uk.

[3] Johnston-Wilder, S. & Lee, C. (2010). Developing mathematical resilience, Paper presented at the BERA Annual Conference, 1-4 September 2010, University of Warwick, Coventry.

[4] Lugalia, M., Johnston-Wilder, S. and Goodall, J. (2013). The role of ICT in developing mathematical resilience in learners. Proceedings of the 7th International Technology, Education and Development Conference, Valencia, Spain, pp. 4096-4105.

[5] Alexander, R. J. (2008). Towards dialogic teaching: rethinking classroom talk. (Fourth Edition) Thirsk: Dialogos.

[6] McLeod, D. B. (1992). 'Research on affect in mathematics education: a reconceptualization', in D. A. Grouws (Ed.) Handbook of research on mathematics teaching and learning (pp. 575-596). New York: MacMillan Publishing.

[7] Elder, Z. (2012). Full on Learning; Involve me and I'll understand. Carmarthen, Wales: Crown House Publishing Ltd.

[8] Lee, C. and Johnston-Wilder, S. (2013). 'Learning mathematics: letting the pupils have their say', Educational Studies in Mathematics, 83(2): pp.163- 180.

[9] Goulding M. and Kyriacou, C. (2007). 'A Systematic Review of the Role of ICTs in Learning Algebra', In D. Küchemann (Ed.), Proceedings of the British Society for Research into Learning Mathematics, 27, 1, March 2007, pp. 36-41.

[10] Chinn, S. (2004). The trouble with maths: a practical guide to helping learners with numeracy difficulties London; New York: RoutledgeFalmer.

[11] Kieran, C. (1992). 'The Learning and Teaching of School Algebra', In D. A. Grouws (Ed.), Handbook of Research on Mathematics Teaching and Learning, pp. 390-419, New York: Macmillan.

[12] Galbraith, P. and Haines, C. (1998). Disentangling the Nexus: Attitudes to Mathematics and Technology in a Computer Learning Environment, Educational Studies in Mathematics, Vol. 36, No. 3, pp. 275-290.

[13] Boaler, J. (2009). The Elephant in the Classroom: Helping Children Learn and Love Maths. Souvenir Press.

[14] Kanja, C. Iwasaki, H. Baba, T. & Ueda, A. (2004). For the Reform of Mathematics Education in Kenyan Secondary Schools, Journal of International Development and Cooperation, Vol. 7, No. 1, pp. 67-75.

[15] Centre for Mathematics, Science and Technology Education in Africa (2009). CEMASTEA Strategic Plan 2009- 2013, Retrieved from website: http://www.education.go.ke/Documents.aspx?department=34&id. Accessed 29 October 2012.

[16] Bruner, J. S. (1960). The Process of Education. Cambridge, Massachusetts: Harvard University Press.

[17] Nardi, E. and 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(3): pp. 345- 367.

[18] Vygotsky, L. S. (1978). Mind in society: the development of higher psychological processes. M. Cole, V. John-Steiner, S. Scribner and E. Souberman (Eds) Cambridge, MA: Harvard University Press.

[19] Bruner, J. S. (1961). 'The art of discovery', Harvard Educational Review, 31: pp. 21- 32.

[20] Gattegno, C. (1970). What We Owe Children: The Subordination of Teaching to Learning. New York: Educational Solutions Worldwide Inc.

[21] Bandura, A. (1989). 'Human agency in social cognitive theory', American Psychologist, 44(9): pp. 1175- 1184.

[22] Brown, M. Askew, M. Baker, D. Denvir, H. and Millet, A. (1998). 'Is the National Numeracy Strategy research-based?' British Journal of Educational Studies, 46(4): pp. 362- 85.

[23] Pickering, A. (1995). The mangle of practice: time, agency and science. Chicago, IL: University of Chicago Press.

[24] Norris, N. and Walker, R. (2005). 'Naturalistic Inquiry', in B. Somekh and C. Lewin (Eds.) Research methods in the social sciences (pp. 131- 137). London; Thousand Oaks; New Delhi: Sage Publications.

[25] Abbot, I., Townsend, A., Johnston-Wilder, S., Reynolds, L. (2009). Deep learning with technology in 14 to 19 year old learners. Coventry: Becta.

[26] Hernandez-Martinez, P. and Williams, J. (2013). 'Against the odds: resilience in mathematics students in transition', British Educational Research Journal, 39(1): pp. 45- 59.

[27] Dane, F. C. (1990). Research Methods. Pacific Grove, California: Brooks/Cole Publishing Company.

[28] Mercer, N. (1994). 'Neo-Vygotskian theory and classroom education', in B. Stierer and J. Maybin (Eds) Language, literary and learning in educational practice: a reader (pp. 92- 110). The Open University: Multilingual Matters Ltd.

[29] Black, P. Harrison, C. Lee, C. Marshall, B. and Wiliam, D. (2003). Assessment for learning: putting into practice. Buckingham: Open University Press.

[30] Edwards, D. and Mercer, N. (1987). Common Knowledge. The development of understanding in the classroom. London: Routledge.