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Bonnett, Victoria M., Yuill, N. and Carr, A. (2017) Mathematics, mastery and metacognition: how adding a creative approach can support children in maths. Educational and Child Psychology, 34 (1). pp. 83-93. ISSN 0267-1611.

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Mathematics, Mastery and Metacognition: How adding a creative approach can support children in maths

Victoria Bonnett, Nicola Yuill & Amanda Carr

Background: Children who hold an incremental view of ability show greater perseverance, improved help-seeking skills and are better able to cope with unexpected challenges. Classroom instruction can influence how children view themselves as learners.

Aim: To explore how mastery-orientated classroom instruction, collaborative learning and metacognitive reflection can foster learner*s' attitudes to their* task performance. We hypothesised that using a mastery-oriented approach within a mathematics curriculum encourages metacognition, improves motivation and helps children achieve an underlying understanding of mathematical concepts thus improving mathematics performance.

Method: This paper reports an eleven-week project aiming to embed problem-solving strategies within a mastery-oriented whole-class environment. Children completed pre- and post- task semi-structured interviews and maths problems in addition to the eleven-week collaborative maths project. Participants were 24 children from a rural primary school in East Sussex, 12 boys and 12 girls (mean age 8 years and 9 months). The interviews are presented qualitatively and a repeated measures analysis of variance on mathematics motivation and performance was conducted.

Findings: The learners showed increased metacognitive reflection on learning strategies as well *as increases in girls' motivation for mathematics*.

Limitations: This is a small sample size and, being conducted within a typical everyday classroom, there were several uncontrolled variables. Although change was evident in both attitude and maths scores, it was difficult to apportion added value to the different variables contributing to the change in maths scores.

Conclusions: *Challenging children's perceptions of mathematics encourage*d greater self-

reflection and increased motivation for girls.

Keywords: mathematics, mastery-orientation, metacognition, reflection, creativity

Introduction

Motivation to participate in school tasks is a fundamental component of school-based learning and with changes to the national curriculum in England the spotlight is currently on attainment in English and maths (Department for Education, 2014). However, children may approach a task with different motivations and beliefs about their ability (Grant & Dweck, 2003). These differences relate to how children view the purpose of learning, either to improve their ability, or demonstrate competence to others, which influences how they cope within a classroom environment (Dweck, 1986).

Achievement Goal Orientation (AGO) provides a framework to understand these differences and this traditionally had a dichotomous split of mastery- and performance orientation, representing cognitive, affective and behavioural differences between learners (Grant & Dweck, 2003). Understanding how children view themselves within the classroom can inform later intervention and teacher planning.

Achievement Goal Orientation

Research suggests that a mastery-orientation supports educational attributes such as greater engagement, requesting appropriate help and seeking conceptual understanding (Ames, 1992; Pintrich, 2003; Elliott & Dweck, 2007). Children who believe that success is achieved with effort are less daunted by failure; effort can always be increased and therefore so can ability (Grant & Dweck, 2003). Performance-oriented learning may result in a more extrinsic approach, the aim being to achieve a higher grade than a peer, rather than improve understanding with increased effort seen as a sign of low ability (Church, Elliot, & Gable, 2001).

Differences in AGO suggest that children may monitor and reflect on their work in different ways; mastery-oriented children may notice the effort they are putting into a task and may be more prepared to switch strategies or apply further effort. Performance-oriented children may spend more time monitoring their peers which means they miss cues regarding their own learning, such as the need to ask for further help. It is these differences which make it important to study AGO within a classroom environment.

Recent addition to the AGO literature includes performance-avoidance and mastery-avoidance goals thus presenting a 2 (AGO) x 2 (approach or avoidant) framework (Harackiewicz, Barron, Pintrich, Elliot, & Thrash, 2002; Pintrich, 2000). Performance-approach orientates the learner to do better than their peers. Therefore, a child holding this orientation will pursue tasks to ensure success over peers. A performance-avoidant motivation will orient a learner to do no worse than their peers. Therefore a child holding this motivation will avoid tasks with a high chance of failure. Both mastery-oriented and performance-approach motivations can lead to positive outcomes whereas performance-avoidance goals are associated with task withdrawal and self-handicapping in order to avoid failure (Harackiewicz et al., 2002). A mastery-avoidance goal indicates fear of failure through not understanding a task, or not learning enough and although presents as a more positive goal than performance-avoidance, may also lead to disorganised studying (Elliot & McGregor, 2001).

AGO is not just an individual trait: classroom structure, school ethos and teacher - pupil relationships also influence how children relate to different classroom tasks (Ames, 1992). Despite differences in dispositional AGO, a mastery-oriented classroom context appears to act as a buffer against possible negative outcomes. The nature of tasks (e.g. test or a learning task) and student grouping (e.g. individual or competitive) can influence how salient particular achievement goals are for children. Ames and Archer

(1988) found that when students perceived the classroom structure as being more mastery-oriented, they reported using more learning strategies and selecting tasks presenting more challenge. Performance-oriented students tended to focus on their perceived ability and attribute failure to the difficulty of the work, which can increase feelings of anxiety and under-achievement.

Metacognitive awareness and AGO

Mastery-oriented children show greater sustained levels of metacognitive awareness (Ford, Smith, Weissbein, Gully, & Salas, 1998). Metacognition is an awareness of your own thinking and involves self-reflection, ability to monitor progress and adapt strategies (Ford et al., 1998). Discussion between peers plays an important role in learning and development of such metacognitive skill. Brown (1988) suggested that children consolidate their learning more effectively when they have to explain their choices, therefore using language to support their understanding. This may contribute to a sense of belonging and feed into perceptions of self-esteem and peer - acceptance (Polychroni, Hatzichristou, & Sideridis, 2012). AGO may influence task conversation and how learning is consolidated.

Classroom learning

An important educational consideration is that differences in motivation, whether dispositional or situational, affect children's strategy use and self-efficacy, which in turn can be influenced by the instructions they receive for a task (Matthews & Rittle-Johnson, 2009; Harris, Yuill & Luckin, 2008). Children receiving performance-oriented instructions in a study by Harris et al. (2008) tended to concentrate more on the task outcome than on discussing good solutions and strategies. This focus on the outcome affects the strategies employed throughout the task with a performance-oriented focus on public success leading to more requests for the answer and less time trying to work it out

(Ford, et al., 1998; Harris et al., 2008). Instructions which encourage children to concentrate on the process of the task rather than the end result lead to increased effort and ultimately improved learning (Schuitema, Peetsma & Van Der Veen, 2011). Failing to understand a task may lead to lack of perseverance, less useful help-seeking and reduced self-esteem (Bonnett, Carr, Yuill, Luckin & Avramides, 2012: Luckin & Hammerton, 2002).

Mathematics learning

Mathematics anxiety can interfere with a child's concentration, as intrusive "I can't do it" thoughts undermine concentration on the task and become a self-fulfilling prophecy (Furner & Gonzalez-DeHass, 2011; Ashcraft, 2002). There is evidence of gender difference in confidence to try alternative strategies and asking questions in a whole-class environment. Dickhauser and Meyer (2006) examined maths attributions in 8 - 9 year old children and found gender differences in attributions. Girls attributed maths success to high ability less than boys did, and attributed maths failure more to low ability than boys did. Interestingly, general ability and grades did not differ between genders. Creating a mastery-oriented atmosphere where collaboration, exploration and self-reflection is encouraged can lead to increased confidence, greater effort and sustained engagement (Blumenfeld et al., 1991; Turner et al., 1998). Furner and Gonzalez-DeHass (2011) suggested that teachers create a climate in which errors are viewed as a useful step towards problem-solving and learners consider themselves part of a community. Increasing a sense of belonging may boost self-esteem and ameliorate anxiety, thus decreasing individual referrals to external professionals for a range of classroom difficulties.

Rationale and aims

The purpose of the current study was to explore a mastery-oriented classroom approach

to learning mathematics and bring creativity to bear on problem-solving strategies within a mathematics environment. Using mathematics within a creative project removed the focus on evaluation and encouraged children to try different strategies to solve problems. This reflected a mastery-oriented approach to learning and allowed discussion and active involvement with the task. This study sought to promote a philosophy of *"I do – and I understand"* (Nuffield Foundation) and maintain a mastery-oriented focus throughout.

To encourage engagement with the processes involved in solving mathematics problem, the mathematics activity was made cross-curricular by linking with the class topic of Ancient Egyptians. In this case, making containers with a correct volume to accommodate the different objects they needed to include. It was proposed that a mastery-oriented approach alongside a high level of involvement with a creative task would be equally helpful for boy and girls, and all abilities, in helping the children reflect on problem-solving strategies.

By using mathematical processes outside a typical mathematics lesson, it was anticipated that children would gain confidence in experimenting with different strategies in reflective ways. It was important to acknowledge the children's ideas and more importantly show that their decisions were incorporated into the project. Autonomy leads to higher levels of interest, engagement and enjoyment and consequently higher levels of achievement (Gagné, Koestner, & Zuckerman, 2000). By using mathematics problem-solving to complete their creative project, children used mathematics in context and learned how to apply mathematical concepts outside the traditional mathematics classroom.

The aims were:

1. To explore mastery-orientated classroom instruction and ways in which collaborative learning and metacognitive reflection can be fostered.

2. To move away from the expectation that learning was about finding the right

answer and to encourage each child's metacognitive thinking in the form of reflection and evaluation.

Method

The project was a collaboration between the school and Creative Partnerships (see acknowledgements). The school employed the author of this paper to evaluate the project, following British Psychological Ethical Guidelines (2009) and to report results to both Creative Partnerships, the school staff and parents. To enable this, the researcher interviewed children at the beginning and end of the project, asked children to complete a mathematics evaluation scale both at the beginning and end of the project and asked the class teacher to set the children mathematics words problems as a pre- and post $-$ test, so as to assess any learning gains. There was no comparison group.

Participants

Participants were a whole class of 24 Year 4 children (12 boys and 12 girls mean age 8:9) attending a semi-rural primary school in East Sussex. Parents were informed about the project by the school and written parental consent for the researcher to interview the children and use data from the study was obtained prior to the study commencing. The children had been involved in selecting the external practitioner: Following a creative lesson delivered by two possible candidates, the children had voted on which idea they preferred. The children were also aware that the lead author on this paper would be present in each session and would provide feedback at the end of the project to themselves, their parents and staff. Verbal consent was requested from the children to meet with the researcher in order to talk about their learning. All children chose to participate. The school had won a small grant from the Creative Partnerships Enquiry Schools Programme with which to fund the project and ran over a period of eleven weeks

with one day a week dedicated to it.

Measures

       Metacognitive reflection. Children were interviewed for ten minutes in groups of 3 (n = 8 interviews) at the start of the project to gather information about the level of awareness of different learning strategies. The researcher asked "What advice could you offer someone as a learner?" This was a deliberately broad question to encourage the children to think about their own learning strategies. Groups of 3 were chosen because we found that this supported higher levels of participation than smaller or larger groups. This interview was repeated at the end of the study with the same groups of 3.

       Mathematics Evaluation Scales. Children completed two 5-point mathematics evaluation scales individually within the whole class environment. These assessed motivation and competence at the start and end of the project. The first scale assessed math motivation from a score of 1, sad face picture– I don't like mathematics at all, to a score of 5, happy face picture– I love mathematics. The second scale assessed perceived math competence, from 1, sad face picture – I'm not very good at mathematics, to 5, happy face picture – I'm really good at mathematics. Children marked where they felt they were along the scale with the middle being explained as "just ok, not sad or happy". These evaluation scales enabled comparison of gender attributions well as whole-class evaluation.

       Mathematics Performance. At the start of the project children completed ten traditional mathematics word problems set by the class teacher and were scored for the number of correct answers and the number of methods displayed. For example; 'Toby has 42 eggs. Each egg box holds 6 eggs. How many egg boxes will Toby need to hold

all the eggs?' Displaying methods whilst working out word problems would indicate an understanding of the process. The children completed these individually in test conditions. The same test was given at the end of the eleven-week study in the same test conditions. One boy did not complete the pre-test and one girl did not complete the post-test due to school absence, therefore they have been omitted from any analysis. These two children took part in the main creative project and mathematics sessions so they are included in the group numbers.

Procedure

The school employed an external visual artist as part of the Creative Partnership grant to introduce greater scope for learning creatively into the classroom. To fulfil both the mathematics and Egyptian parts of the project the children designed and made canopic jars, containers used by the Ancient Egyptians to store internal organs after the death of an individual. The children received instructions to research, design and make canopic jars. The visual artist encouraged discussion between the children regarding their design, size and materials. This was initiated with a "brainstorm" session with the children suggesting ideas and the visual artist writing them on a large piece of paper. The children discussed concepts such as circumference and capacity and researched suitable materials, quantities and designs.

The children were then split into two groups and remained in these groups for the length of the project. The project ran one day a week for eleven weeks. Each group worked for half a day in each session and then swapped so that both groups had a creative session and a mathematics session each week. In the creative session, children worked on the canopic jar design and making their designs and in the mathematics session, children took part in a more formal mathematics session followed by a group discussion with the

class teacher.

The children had to solve a range of mathematics word problems written by the teacher based on the jar designs. As the children were going to make their jars, the problems were based on working out the materials the children would need to complete their jars. For example, "Your pot is going to be made out of 6 plywood rectangles. Each rectangle will measure 20cm x 45 cm. Plywood is sold in 100 x 100cm squares. How many pieces of plywood will you need to buy to make your pot?" This enabled the children to understand the relevance of their calculations.

In the creative sessions the children creatively explored mathematical concepts, such as circumference and capacity, to encourage understanding of the underlying principle. For example, when measuring the capacity of their trial pots, each child filled their pot with different objects such as pencils or building blocks and then recorded how many were in the pot. The children were then able to discuss with confidence the capacity they would require of their canopic jars and this term became contextually meaningful.

The project was child-led with the children choosing their designs, leading discussions and finding the mathematical methods which were most intuitive for them. Some children chose to sit with a pen and paper and make calculations, others chose small blocks to physically represent the numbers involved, whilst others chose a times table square depicting all the tables as a prompt to enable calculations. The continued emphasis was on the process of problem-solving rather than the end result.

Early in the project the children explored different shapes for their pots using newspaper and sticky tape. The visual artist had a specific reason for this which steered the children towards a mastery-oriented approach;

 "If you use craft paper and let a child take their pot home, they start thinking differently about it, they start making it for someone else and become less confident about

trying different things, less sure about making mistakes".

Using newspaper emphasised a 'trial and error' approach and simply to try out ideas rather than create a finished product. This reduced the need to compare their pot with that of their peers or to hold in mind potential evaluation by a parent or carer. It was important that the children understood the processes they were using to solve the word problems, enabling them to reflect on their learning and understand that they could try again.

To encourage the children to persevere and seek understanding during the formal mathematics sessions, each child was given a "Helping Hints" card with specific actions to encourage perseverance. These were focused on the process of problem-solving.

1) I can read through the problem again

2) I can find something in the classroom to help me.

3) I can listen to my partner's ideas.

4) I can think about similar problems I have solved

These were to offer prompts when the children reached the "just can't do it" stage when they sometimes focus on a lack of understanding rather than thinking of strategies. Early on, one child became unable to move forward and when asked what she could do, her reply-- "give up?" -- indicated that offering a strategy to encourage perseverance would be beneficial.

Whilst discussing methods one child commented that they thought using the usual classroom displays, such as a times table chart or number lines, would be "cheating and [the teacher] puts them there to test us". It was useful for the teacher to then lead into a discussion of possible help which could be sought within the classroom. Listening to a partner's ideas encouraged the children to put their thoughts into words as well as to listen to an alternative perspective. Thinking about similar problems they have solved is a positive statement focusing the children on the calculation within the mathematics

problem. It was hoped that the children could then work towards an answer and more importantly, to understand how they arrived at that answer.

The emphasis of the lessons was on the methods the children used to find answers. After each session, creative or formal, there was a group discussion in which the children discussed how they had arrived at solutions and what they thought they had learnt.

Results

Metacognitive reflection

The responses to the initial interviews were collated and analysed thematically by the first author. Thematic analysis is a widely-used method of qualitative analysis used to address open-ended responses and can be applied to large or small data sets (Braun & Clarke, 2006).

The process of analysis included coding responses to the question "What advice could you offer someone as a learner?" in order to develop and group common patterns between interviews. The children used a fairly small range of words and ideas, which aided semantic grouping; this initial grouping formed the main themes following inter-rater review with the co-authors (Braun & Clarke, 2006).

This process resulted in three overarching themes;

1) Work as a team

   a. For example, *"We should work together"*; *"You can use teamwork"*.

2) Listen to the teacher

   a. For example, "The teacher will tell you what to do, so you have to listen to that", *"You need to listen to the teacher"*

3) Talk to each other

   a. For example, "You can talk to your *partner", "You can talk on your table"*

There were on average two distinct themes mentioned in each group. Children tended to mention ideas in terms of general classroom expectations rather than describing their own individual learning strategies.

During the final interviews, the researcher repeated the same question to the children. The children's advice contrasted with the initial interviews and showed some insightful knowledge into their learning. The comments were more diverse and did not fit into the initial three themes. Additionally, the children generated on average four distinct themes per group. The same process of analysis was applied and three additional themes were derived from the data (Table 1). Following inter-rater review, the final overarching themes were shared with the class-teacher for any additional consideration.

The children appeared more reflective and better able to suggest strategies individual to themselves. Interestingly, the category 'talk to each other' was absent from these interviews and replaced with more references to 'listening to each other'.

Table 1 here

Mathematics Evaluation Scales

In order to explore gender differences in attributions of competence and motivation, as detailed in the extant literature, and possible further impact of mastery-oriented instructions, the evaluation scales were analysed by gender using non-parametric analysis: Mann-Whitney test.

Girls (Mdn = 3) differed from boys at the beginning of the project, rating themselves less competent than boys did (Mdn = 4) at mathematics, $U = 15.50$, $p < .005$, $r = -.66$. Boys (Mdn = 4) also scored higher on motivation than girls (Mdn = 3), $U = 25.5$, $p < .01$, $r = -.52$. The post-intervention evaluation scales showed no significant differences

between boys and girls for either of these variables: Girls (Mdn = 4) and boys (Mdn = 4) for competence and girls (Mdn = 4) and boys (Mdn = 5) for motivation.

A Wilcoxon test comparing pre and post measures showed that there was no significant change in boys' perceived competence or motivation on either scale, but the girls showed a significant increase in perceived math motivation evaluation between pre(Mdn 3) and post-test (Mdn = 4), T = 3, p < .05,r = -.46.

Mathematics Performance

A repeated measures analysis of variance on mathematics performance on pre- and post-test scores was conducted. This showed a significant improvement in scores, $F_{(1,20)} = 13.40$, p< .01(Table 1). More crucially, there were significantly more methods displayed by the children on their post-test paper than on the pre-test, $F_{(1,20)} = 59.06$ p < .001). There were no gender differences in these results and all analysis satisfied assumptions of sphericity.

TABLE 2 here

Discussion

This project aimed to explore mastery-orientated classroom instruction, collaborative learning and metacognitive reflection using a whole-classroom approach incorporating all abilities.

Children improved their mathematics skills through the course of the project. More significantly for the project, they showed a better understanding of the importance of displaying methods, and more specific metacognitive reflections on learning. These improvements were also accompanied, for girls, by an increase in liking for mathematics (motivation).

The boys' opinions of their mathematics ability were concordant with their initial mathematics performance results, whereas girls scored higher than they had predicted, thus underestimating their ability. These results are supported by previous research, which indicates that girls generally achieve slightly more than boys during primary school yet boys tend to have more positive competence beliefs about their ability (Dickhauser, & Meyer, 2006; Eccles, Wigfield, Harold, & Blumenfeld, 1993). Mathematics anxiety is also higher amongst girls than boys (Ashcraft, 2002).

As there was no control group, it is not possible to estimate how much improvement was due specifically to this project, and it is perhaps unsurprising that mathematical skill and use of methods increased as these were a focus throughout the eleven weeks. However, it is encouraging that some differences between boys and girls had disappeared by post-intervention evaluation; girls' rating of their motivation was equal to that of the boys. This suggests that the approach was especially beneficial for girls in changing perceptions about mathematics as a subject.

 Initially, some children wanted defined parameters rather than an open-ended creative task. By encouraging creativity, the children felt freer to experiment and "trial and error" became "trial and improvement". Focusing on strategy use encouraged an underlying understanding of the mathematical process and this may have contributed to the change in girls' motivation for mathematics.

During the classroom mathematics sessions the children worked in pairs and the class teacher encouraged the children to find things in the classroom that would help them work out the answers. The teacher's mastery-orientation instruction was aimed at supporting the children to 'have a go' in a subject that some perceived to be difficult. One particular child commented at the beginning of the project;

"Learning with [the visual artist] is fun because you can do it in rough, you don't have

to worry about making mistakes….can't do mathematics like that, have to be right"

Promoting a whole classroom mastery-oriented environment can encourage the idea that maths can be 'like that' - a subject in which mistakes can be a useful part of the learning process. This may be particularly useful for performance-avoidance children, or those with low perceived competence, who tend to 'give up' in the face of challenge. Mastery-oriented instruction from the class teacher can promote greater learner collaboration and a willingness to cooperate with a partner, as the focus is on learning, rather than peer comparison. The children appeared to have embraced this opportunity throughout the project and despite initial reservations about having no set parameters, the class worked effectively together to produce their designs. The children moved from understanding their learning in terms of ability to one in which they were able to discuss with each other their ideas, listen and try different options. The creativity, cooperation and task discussion with both their peers and the class teacher seemed to support a wider range of problem-solving strategies in the mathematics post-test and more reflective and specific learning advice.

The metacognitive reflections in the final interviews were very different to the initial interviews in both quality and quantity of response. This indicates greater thought from each child about their own learning strategies; the learning had more personal meaning to the child. The extended themes in the post-interviews suggested some internalising of the 'helping hints' cards and the teacher's post-task discussion groups in which different strategies were volunteered by the children and discussed. These reinforced the mastery-oriented instructions and focused on listening to each other, trying again (persistence) and help-seeking. This is concordant with the AGO literature, which suggests that mastery-oriented learning promotes task focus, persistence and self-regulation and in turn, intrinsic motivation, as encouraged by mastery-oriented learning, is related to higher

levels of metacognitive awareness (Grant & Dweck, 2003; Ames, 1992).

Changing the classroom context may be an effective approach for including children of all abilities. However, setting aside a whole day for mathematics may not be achievable within a prescriptive, performance-driven curriculum. This project was feasible through a small grant; adding such a creative aspect of an artist requires additional resources which may not be available without external funding. However, it is possible to consider mastery-oriented instructions within the classroom and partner children of different abilities. Additionally, the class teacher was keen to link the maths word problems to the children's project. Linking activities across the curriculum enabled this approach and appeared to foster acceptance thus possibly reducing the need for additional individual work with lower-achieving children. Whole-class interventions and strategies create a learning environment beneficial for all children, encouraging those with low perceived competence whilst also providing challenge to those who need it and may be a more cost-effective use of limited resources.

Linking this work with mathematics may have helped alleviate typical mathematical worry and allowed all children to contribute ideas and thoughts freely. The creative project gave the word problems context, and gave the children concrete examples, enabling them to discuss the underlying mathematical process with increased confidence. The group discussions gave the teacher opportunity to highlight particular areas of interest to consolidate learning and to ensure that the class were reaching understanding. Giving the children prompt cards with "helping hints" gave them a strategy when they became stuck and also encouraged the children to think about the process of problem-solving. Having choice within their learning allowed children to plan and adapt their actions to the task and being able to do this successfully is a crucial aspect of self-regulated learning and metacognitive skill (Postholm, 2010).

This whole-class intervention fostered a 'sense of belonging' as discussed by Ames in which she described children as being an 'important and active participant' (p. 263, Ames, 1992) and creating a connection with their learning. This was achievable for learners at all levels and may subsequently reduce the need for individual assessment.

Strengths and limitations

A strength of this research is in using a real life learning situation, but within this is a limitation that it is not easy to see which variables had the main influence on the results, for example girls' mathematics opinion. It is possible that it was the amalgamation of approaches that ensured the success of the project, or solely the creative activity.

To work creatively presents challenges. Being able to split the class into two groups was ideal, but not always feasible given time and space constraints present in many schools. A further challenge is to ensure that areas of the curriculum which need to be more formally taught are done so, whilst incorporating creativity to allow children exploration time.

Conclusion

Challenging children's perceptions of mathematics enabled them to be more flexible in their learning. Allowing children to contribute so much to their own learning encouraged feelings of autonomy, which is important for increased interest and perseverance (Gagné et al., 2000). Whole-class interventions and mastery-oriented instructions encourage peer-acceptance and may be a first step before individual assessment.

One of the main reasons that this was a successful project was the willingness of the school and particularly the class teacher to take a step back, not plan an outcome and just see where the process went. The role of AGO continues to be an interesting and varied area of research and whilst providing some insight into classroom behaviour, the research

presented in this paper also gives rise to further questions and directions.

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