

Using low-stakes quizzing and interleaving to promote learning and retention of information in primary mathematics

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Executive summary

Description of the innovation

This innovation project investigated the impact of using low-stakes quizzes and spaced practice and/or interleaving on mathematics attainment in Year 5 pupils in a large three-form entry primary school.

We designed a nine-week programme that incorporated spaced practice and interleaving in order to measure the impact of these approaches on the learning and retention of information in primary mathematics as measured by the CEM General Mathematics standardised test. In order to deliver spaced practice and/or interleaved practice we carried out low-stakes quizzing using the Learning by Questions (LbQ) platform.

Summary of the evaluation

Sixty-nine Year 5 pupils in three parallel mixed-ability classes participated in the evaluation. All pupils attended a large primary school based in Sandwell. The percentage of pupils eligible for pupil premium at the school is 39%, which is well above the national average.

The three classes were randomly assigned with a coin toss to each of the conditions described below:

- **Control class** – business-as-usual. Paper-based quizzes were presented after a topic was taught in lessons in a blocked fashion corresponding to the topic which had just been taught in class.
- **Intervention class 1** – LbQ quizzes with spaced practice. For the purposes of this project we define spaced practice as children only revisiting the material on one occasion after the initial teaching but with a delay of two weeks after it was taught. Post-topic quizzes were therefore presented to children in lessons with a delay of two weeks between classroom teaching and quizzing.
- **Intervention class 2** – LbQ with spaced practice and interleaving. As for Intervention 1, there was a delay of at least two weeks between classroom learning and testing, but in addition maths topics were tested in an interleaved fashion rather than blocked practice. In Intervention 2, teachers interleaved practice of different types of mathematical content so that newer tasks were mixed together with revision of earlier lessons and maths topics. This meant that key topics were presented multiple times to pupils before the final post-test in this group.

Summary of findings

The results suggest that there is promising evidence that interleaving had a positive effect on mathematics progress compared to both the control and spacing groups (Effect Size Intervention 2 (spacing + interleaving) vs Intervention 1 (just spacing) +0.80; Effect Size Intervention 2 (spacing + interleaving) vs Control +0.78). The control group performed slightly better than Intervention 1 (just spacing) but there was a small effect size for this comparison (-0.08).

Introduction

Description of the problem

Teachers aim to ensure that information is learned and understood during a lesson, unfortunately a lot of the material may be forgotten over subsequent weeks. This is reflected in the performance of our Year 5 pupils who are struggling to retain mathematical information over the longer term. Both 2017 KS2 SATS data for mathematics and CEM standardised assessments completed at the start of the academic year for the current Year 5 cohort, indicate that mathematics attainment data is below the national average. We therefore wanted to investigate whether using quizzes and spaced practice can promote learning and retention of information in primary mathematics resulting in improved performance on the CEM General Mathematics standardised test.

Review of existing research

The advantages provided to memory by the distribution of multiple practice or study opportunities are among the most powerful effects in memory research (Benjamin and Tullis, 2010).

While some forgetting may be inevitable, as a process it is well understood by memory researchers, and steps can be taken to reduce it. One simple option is to manipulate the timing of study activities, and in particular to increase the gaps of time between initial learning and consolidation work. The 'spacing effect' is a phenomenon first observed during the early days of psychology in the 1880s; spacing out learning over time (sometimes called 'distributed practice') has the potential to double retention over timescales relevant to school or college courses (Mozer et al, 2009).

A number of studies have found that retrieval practice in authentic classroom settings improves long-term learning (Agarwal et al, 2012). Studies have also revealed that using retrieval practice resulted in increased retention, particularly when retrieval was equally spaced and the initial test was delayed (Karpicke and Roediger, 2007). Over longer timescales, repetition may serve to remind learners of their earlier learning experiences, thereby activating relevant episodic memories and making them easier to access in future (Benjamin and Tullis, 2010). Moreover, several recent studies have shown that testing itself not only enhances learning, it also reduces the rate at which information is forgotten. (Roediger and Karpicke, 2006).

Research with practical implications for the classroom

- Practice is essential to learning new facts, but not all practice is equivalent (Ericsson, Krampe and Tesch-Römer, 1993).
- Teachers can space practice over time, with content being reviewed across weeks or months, to help students remember that content over the longer term (Cepeda et al, 2006).
- Teachers can explain to students that trying to remember something makes memory more long-lasting than other forms of studying. Teachers can use low- or no-stakes quizzes in class to do this, and students can use self-tests (Agarwal, Bain and Chamberlain, 2012; Pashler et al, 2007).

- Teachers can interleave (ie, alternate) practice of different types of content. For example, if students are learning four mathematical operations, it is more effective to interleave practice of different problem types, rather than practise just one type of problem, then another type of problem, and so on (Pashler et al, 2007; Rohrer, Dedrick and Stershic, 2015).

Description of the innovation

We designed a study programme that incorporates spaced practice and interleaving in order to improve learning in mathematics. Rather than the standard practice of issuing blocked assessments on the same day or week that a topic has been taught, in the intervention groups this was replaced by a process of delaying each such task by at least two weeks, at no extra time cost to the teacher.

Intervention group 1 were taught a topic and then had one opportunity to retrieve that information during an online quiz two weeks later.

Intervention group 2 received assessment tasks that were both spaced and interleaved (ie, content from previous weeks was mixed in to subsequent quizzes with a delay of at least 2 weeks). This meant that children were asked to retrieve information on multiple occasions throughout the project during the online quizzes in Intervention 2.

We gave pupils low-stakes quizzes using the Learning by Questions platform to allow regular opportunities for material to be revisited. Correct-answer feedback was provided to pupils as they worked. The school uses the White Rose maths hub's long-term planning so the assessment materials available were closely aligned to our taught curriculum.

We used a three-armed design with a control group (no online quizzes) and two different intervention groups (Intervention 1: online quizzing with spaced practice and Intervention 2: online quizzing with spaced practice and interleaving of topics).

All pupils (control and intervention classes) completed a pre-test assessment. This was a CEM Incas standardised test in mathematics.

Pupils in all three groups undertook a series of low-stakes quizzes throughout the intervention period. Pupils in the control group continued with business as usual, which involved a topic being taught in class and a blocked quiz/assessment on that topic immediately afterwards.

The quizzes for Intervention 1 and Intervention 2 groups were carefully selected so that:

- a. There was a delay of two weeks between classroom learning and testing for Intervention 1.
- b. There was a delay of two weeks or longer between classroom learning and testing for Intervention 2 due to interleaving of earlier classroom content in later quizzes.
- c. In Intervention 1 the low-stakes quizzes contained blocked content linked to the mathematical content recently taught in lessons. In Intervention 2, teachers interleaved practice of different types of mathematical content so that newer tasks were mixed together with revision of earlier lessons/maths topics. This meant that key topics were presented multiple times to pupils before the final test in this group.

All pupils undertook a post-test, which again took the form of a CEM Incas standardised test in mathematics.

Research question

What impact does using spaced practice and/or interleaving within low-stakes quizzing have on Year 5 pupils' mathematics attainment over a period of nine weeks?

Method

The evaluation took place in Year 5 at an urban primary school in Sandwell, West Midlands. The school is three-form entry with a pupil premium percentage of 39%. Sixty-four pupils participated in the evaluation in total and no parents chose to opt their child out of participation.

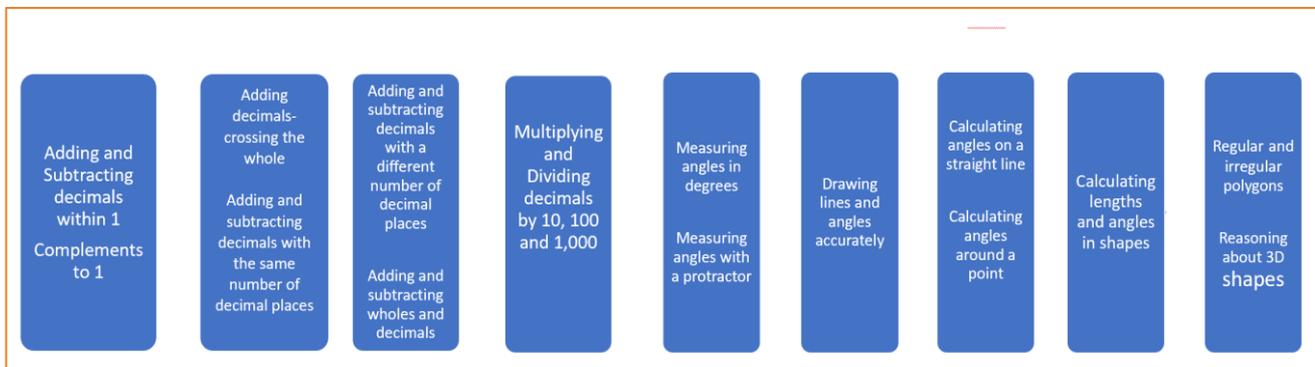
Assignment to condition

The three classes were randomly assigned with a coin toss to each of the conditions.

Innovation

Pupils undertook a pre-test baseline the week before the project started.

All teachers in Year 5 followed the same medium-term plan and taught the same weekly mathematics topics for the duration of the project as follows:



The classes were randomly assigned to the conditions below:

- **Control class** – business-as-usual. Paper based quizzes were presented after a topic was taught in lessons in a blocked fashion corresponding to the topic which had just been taught in class.
- **Intervention class 1** – LbQ quizzes with spaced practice. For the purposes of this project we define spaced practice as children only revisiting the material on one occasion after the initial teaching but with a delay of two weeks after it was taught. Post topic quizzes were therefore presented to children in lessons with a delay of two weeks between classroom teaching and quizzing.
- **Intervention class 2** – LbQ with spaced practice and interleaving. As for Intervention 1, there was a delay of at least two weeks between classroom learning and testing, but in addition maths topics were tested in an interleaved fashion rather than blocked practice. In Intervention 2, teachers interleaved practice of different types of mathematical content so that newer tasks were mixed together with revision of earlier lessons and maths topics. This meant that key topics were presented multiple times to pupils before the final post-test in this group.

	Lesson topic 1	Lesson topic 2	Lesson topic 3	Lesson topic 4	Lesson topic 5	Lesson topic 6	Lesson topic 7	Lesson topic 8		Lesson topic 9	
Control	Quiz at end of week on topic 1	Quiz at end of week on topic 2	Quiz at end of week on topic 3	Quiz at end of week on topic 4	Quiz at end of week on topic 5	Quiz at end of week on topic 6	Quiz at end of week on topic 7	Quiz at end of week on topic 8		Quiz at end of week on topic 9	
Intervention 1			Quiz at end of week on topic 1	Quiz at end of week on topic 2	Quiz at end of week on topic 3	Quiz at end of week on topic 4	Quiz at end of week on topic 5	Quiz at end of week on topic 6		Quiz at end of week on topic 7	
Intervention 2			Quiz at end of week on topic 1	Quiz at end of week on topic 1 and 2	Quiz at end of week on topic 1, 2 and 3	Quiz at end of week which interleaves all prior topics taught to this point	Quiz at end of week which interleaves all prior topics taught to this point	Quiz which interleaves all prior topics taught to this point	Quiz which interleaves all prior topics taught to this point	Quiz which interleaves all prior topics taught to this point	Quiz which interleaves all prior topics taught to this point

The project took place over nine weeks in the summer term. We wanted to test how a spaced and a spaced and/or interleaved approach might work in an ordinary school classroom.

At the start of the term training was delivered to teachers. To encourage implementation validity, we did not go into detail about the theory of spaced practice and interleaving with class teachers during training in order to avoid overstating which group we expected to see the most success in. The training session focused on the use of the LbQ system (delivered by trainers from Learning by Questions) so that teachers were familiar with how to use the system.

The training also included some information about the more general testing effect on memory and a broad outline of the project and some guidance on the planning and assessment process during the project. The schedules for testing in each group were provided to teachers.

Pupils then completed a post-test assessment at the end of the project.

Outcome measures

1. All pupils (control and intervention classes) completed a pre-test assessment at the start of the summer term. This was a CEM Incas standardised test in mathematics which is automatically marked online.
2. All pupils took a post-test after nine weeks at the end of the summer term, which again took the form of a CEM Incas standardised test in mathematics which is an adaptive test that is automatically marked online.

The CEM Incas assessments provided us with age-equivalent scores for general mathematics. The pre and post-test assessments were equivalent but not identical. The test is an online

adaptive test. This means that initial questions are presented depending on the child's age and the difficulty of subsequent questions presented varies depending on the child's performance on previous questions.

All classes covered the same material in lessons, and though both the pre- and post-test were a general maths test (ie, not specifically on the topics covered during the term), no group should be disadvantaged.

Process evaluation

We carried out a process evaluation alongside the impact evaluation of mathematics attainment to help us understand if the innovation was delivered as intended, to gather teacher and pupil views of the innovation, and also to gather teacher and pupil perceptions of things that went well or could be improved.

To achieve this there were a number of aspects to the process evaluation:

1. Over the course of the nine-week evaluation, a classroom observation was conducted of both of the innovation groups and the control group and regular online audits of LbQ were also carried out to check that the intervention was being delivered as intended. During the online audit the LbQ quizzes were reviewed and compared with the medium-term plan for lesson content to make sure that Intervention 1 were receiving spaced practice and Intervention 2 were receiving spaced and interleaved practice during the quizzes. The paper-based control quizzes were also reviewed to make sure that these were neither spaced nor interleaved.
2. With the support of the IEE we developed both a pupil focus group interview schedule and a teacher pre- and post-project questionnaire. The pupil focus groups aimed to gather pupil perceptions of the innovation. These children were randomly selected by picking names from a hat and the focus groups were led by the project lead.
3. Teachers also completed an online pre- and post-project questionnaires to gather teacher perceptions of the innovation. All teachers completed all questions on the pre-project questionnaire. Please see Appendix 1 for the teacher surveys and Appendix 2 for the pupil focus group questions. The post-project survey included some additional questions for the teachers of Intervention 1 and Intervention 2 and these are indicated.

Cost

The cost per pupil to deliver the project was £43.75. Please note this does not include the cost of the tablets or LbQ platform.

Budget item	Amount
Supply cover for training and planning time	£1,550
Technical set up and network manager cost	£500
Standardised tests	£750
Total expenditure	£2,800

Analyses

What impact does using spaced practice and/or interleaving within low- stakes quizzing, and in particular spaced practice and/or interleaving, have on Year 5 pupils' mathematics attainment over a period of nine weeks?

The CEM Incas test provides us with a standard age score. We calculated the mean pre-test, post-test and progress scores for each group and then calculated effect sizes to compare the progress of the three groups (Intervention class 2 vs Intervention class 1, Intervention class 1 vs control and Intervention class 2 vs control).

Results

	Control (n = 24)	Intervention 1 (n = 22)	Intervention 2 (n = 23)
Pre-test group mean (months)	106.58	116.91	116.04
Post-test group mean (months)	108.42	118.36	122.26

	Control (n = 24)	Intervention 1 (n = 22)	Intervention 2 (n = 23)
Group mean progress (months)	1.83	1.45	6.22

Effect sizes

Intervention class 2 vs Intervention class 1	+0.80
Intervention class 1 vs control	-0.08
Intervention class 2 vs control	+0.78

The results suggest that there is promising evidence that interleaving had a positive effect on mathematics progress compared to both the control and spacing groups (Effect size Intervention 2 (spacing + interleaving) vs Intervention 1 (just spacing) +0.80; Effect Size Intervention 2 (spacing + interleaving) vs Control +0.78). The control group performed slightly better than Intervention 1 (just spacing) but there was a small effect size for this comparison (-0.08).

Process evaluation findings

The lesson observations completed during the course of the project and the audits of both online and paper-based quizzes showed the project was implemented as intended.

The process evaluation also revealed positive perceptions of both the Learning by Questions platform and the use of spaced practice and interleaving by teachers and pupils.

Teachers in the intervention groups reported that they felt more confident in both the teaching of mathematics and the use of ICT after the project whilst the teacher of the control group remained constant in these ratings.

	Pre-intervention mean	Post-intervention mean
On a scale of 1 to 10, how confident do you feel about teaching mathematics?	7.5	8.5
On a scale of 1 to 10, how confident do you feel about using ICT in your mathematics teaching?		

In addition, teachers provided a number of positive perceptions of the use of spaced practice and interleaving. The teacher of the interleaving group reported that the approach was especially beneficial for low prior-attainers. Comments included:

‘It was really useful to keep revisiting topics for a short session each week to keep them fresh in the children’s minds. I would use a resource like the LbQ again to provide spaced practice if it were available as it was really useful’

(Intervention 1)

“Children are able to answer questions from a range of mathematical concepts when we revisited previously taught material. Assessment results show systematic improvements in mathematical attainment.” (Intervention 2)

“Some children appear much more secure in their understanding after using an interleaved approach.” (Intervention 2)

“Children are excited to do maths and look forward to using LbQ. They are more confident in talking about what they don’t understand and asking for help from their peers.” (Intervention 2)

Six pupils took part in a pupil focus group after the project. The pupils also reported very positively on the approach and all children in the interleaving group reported that they felt much more confident after using LbQ. Comments included:

“I prefer the maths lessons this term to the ones before. This way of learning teaches us more and it gives us feedback so we know if we need help.” (Intervention 2)

“I found the maths test easier at the end of the project than the maths tests before because practising on LbQ helped a lot and improved my work.” (Intervention 2)

“I like that you get feedback which tells you where you have gone wrong so you realise your mistake.” (Intervention 1)

Discussion/Conclusion

Overall the results suggest that there is promising evidence that interleaving can have a positive effect on mathematics progress compared to both the control and spacing groups.

The results revealed that the class who received both interleaving and spaced practice showed a mean improvement of 6.22 months over a nine-week period, compared to the control group and the spaced practice group who improved by 1.45 months and 1.83 months respectively.

Although we do not know if these results are statistically significant or not based on the analysis completed, it does indicate that the approach is promising and worth investigating further, perhaps by scaling up the evaluation to involve another comparable school or for a longer period of time.

It was unexpected that the control group showed slightly better progress than Intervention 1 (just spacing) but there was a small effect size for this comparison and it is unlikely that this would be significant (Effect size -0.07). However, it is noted that the control group pre-test mean (106.58) was lower than both of the Interventions groups (Intervention 1 (116.91) and Intervention 2 (116.04)) where we would expect equivalent scores as the classes were mixed ability teaching groups. Among other things, this may have meant the teaching and support that this control class received may have been different to the other two groups, even if this happened subconsciously or unintentionally.

It would be interesting to explore this finding further.

Limitations

The main limitation for this study is that each group was taught by a different teacher and so the quality of teaching was not controlled for. It would be interesting to compare two classes who were taught by the same teacher using either business as usual or spacing and / or interleaving to compare the impact but logistics did not allow this in the current study.

In addition to this, the school has joined the Collegiate Academy Trust during the academic year and so there may be other changes to teaching practice which are unaccounted for. However, since all three classes were from within the same school and year group we believe these differences will be the same across all three conditions.

The small sample size and the fact the evaluation was carried out in one school limits the generalisability of the findings. We would also like to try the approach with a larger number of pupils and analyse the performance of different groups such as pupil premium pupils or prior attainment.

The mean control group pre-test score was much lower than those of Intervention groups 1 and 2. This suggests that the groups may not have been equivalent before the intervention. Among other things, this may have influenced the teaching and support pupils in the control group received outside the intervention.

Implications for practice

The findings of this study suggest that it may be useful for school leaders and teachers to review the way that assessments and low stakes testing are used during mathematics teaching.

We would like to explore this over a longer time period in mathematics and also evaluate the impact in other subjects such as science.

Implications for further evaluation

The generalisability of the findings is limited by the small sample size of pupils from one school. It would be beneficial to replicate the study with a larger sample size of pupils over a number of schools. Evaluating the approach on a larger scale would allow sub-group analysis of a larger sample size of pupils to answer the questions:

What is the impact for high prior-attaining pupils?

What is the impact for low prior-attaining pupils?

What is the impact for pupils in receipt of pupil premium?

What is the impact for girls/boys?

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Appendix 1

Pre- and post-project teacher survey

Teacher pre-intervention survey

This short survey is for teachers taking part in the innovation funding project led by Shireland Collegiate Academy. It should take no longer than 15 minutes to complete and your answers will be kept confidential.

1. What is your name?

2. What is your gender?

3. What is your age?

Under 25 years

25-34

35-44

45-54

55 and over

4. How long have you been teaching?

Less than a year

1-5 years

6-10 years

11-15 years

15 + years

5. What is your highest qualification in mathematics?

Up to GCSE or equivalent

A-level

Degree

Masters/PhD

Other (write in)

6. Over the past six weeks, what proportion of your mathematics lessons have involved the direct use of ICT (eg. computers, laptops, tablets)?

Answers in block of 10% eg. 0–10%, 10–20% etc

7. Over the last six weeks, how often have you used the following resources in mathematics lessons?

	All lessons	Most lessons	Some lessons	A few lessons	Never
Maths textbooks					
Maths worksheets					
Maths websites					
Self-marking maths activities					
Interactive whiteboard					
Handheld tablets or devices					
Laptops or PCs					

8. In your view, how useful are the following teaching resources?

	Very useful	Mostly useful	Somewhat useful	Not useful	Don't know
Maths textbooks					
Maths worksheets					
Maths websites					
Self-marking maths activities					
Interactive whiteboard					
Handheld tablets or devices					
Laptops or PCs					

9. On a scale of 1 to 10, how confident do you feel about teaching mathematics?

- 1 No confidence
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 Extremely confident

10. On a scale of 1 to 10, how confident do you feel about using ICT in your mathematics teaching?

1 No confidence

2

3

4

5

6

7

8

9

10 Extremely confident

11. How would you describe your usual approach to assessment / use of tests in mathematics? Please describe the type and frequency of tasks set and how this relates to the work completed in the classroom.

Free text

Thank you for taking the time to complete this survey.

Teacher post-intervention survey

This short survey is for teachers taking part in the innovation funding project led by Shireland Collegiate Academy. It should take no longer than 15 minutes to complete and your answers will be kept confidential.

1. What is your name?

2. What is your gender?

3. What is your age?

Under 25 years

25-34

35-44

45-54

55 and over

4. How long have you been teaching?

Less than a year

1-5 years

6-10 years

11-15 years

15 + years

5. What is your highest qualification in mathematics?

Up to GCSE or equivalent

A-level, Degree, Masters/PhD

Other (write in)

6. Over the past six weeks, what proportion of your mathematics lessons have involved the direct use of ICT (eg. computers, laptops, tablets, and interactive whiteboards)?

Slider showing percentage range

7. Over the last six weeks, how often have you used the following resources in mathematics lessons?

All lessons

Most
lessons

Some
lessons

A few
lessons

Never

Maths textbooks

Maths worksheets

Maths websites

Self-marking maths activities

Interactive whiteboard

Handheld tablets or devices

Laptops or PCs

8. In your view, how useful are the following teaching resources?

Very
useful

Mostly
useful

Somewhat
useful

Not useful

Don't
know

Maths textbooks

Maths worksheets

Maths websites

Self-marking maths activities

Interactive whiteboard

Handheld tablets or devices

Laptops or PCs

9. On a scale of 1 to 10, how confident do you feel about teaching mathematics?

1 No confidence

2

3

4

5

6

7

8

9

10 Extremely confident

10. On a scale of 1 to 10, how confident do you feel about using ICT in your mathematics teaching?

1 No confidence

2

3

4

5

6

7

8

9

10 Extremely confident

11. How would you describe your usual approach to assessment / use of tests in mathematics? Please describe the type and frequency of tasks set and how this relates to the work completed in the classroom.

Free text

(The following questions were only given to teachers in the two intervention groups)

12. How, if at all, has your maths teaching changed from the period before this project? What do you do differently now?

13. Do you feel pupils' ability to retain their maths learning changed at all? (If yes, why do you say that? Do you have any evidence for that?)

14. How do you perceive your pupils' engagement in class? Has it changed? How?

15. Do you think pupils' attainment in maths will improve as a result of this project? (If yes, why do you say that? Do you have any evidence for that?)

16. Could you tell me whether you, as a teacher, have benefited from the project?

17. Are there any groups or types of pupils who you think have benefited more from the programme? (eg. high achievers, low achievers)

18. What do you consider have been the main challenges of the project?

19. What, if anything, has helped you to implement LbQ?

20. Were there any unexpected consequences of the project, either for you or your pupils?

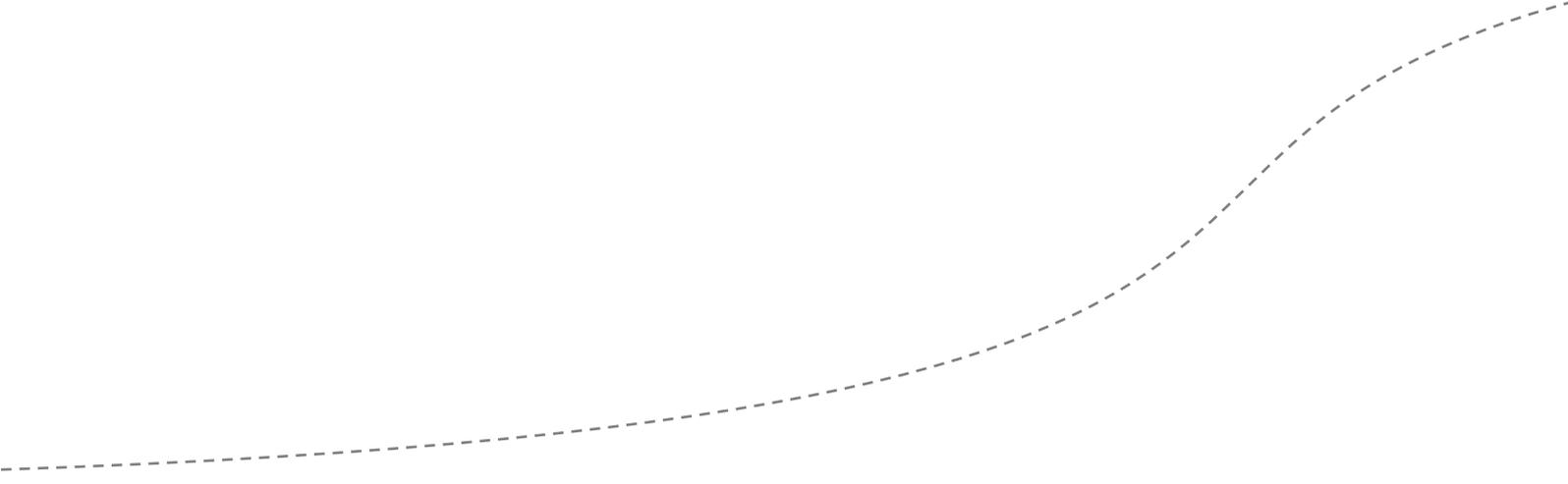
Thank you for taking the time to complete this survey.

Appendix 2

Questions for pupil focus groups

1. On a scale of 1 to 10, how confident do you feel about mathematics?
2. Which best describes how your confidence in mathematics has changed after using LbQ?
 - I feel much more confident
 - I feel a bit more confident
 - My confidence is the same as before
 - I feel a bit less confident
 - I feel much less confident

(Pupils will be given question 1 and 2 on paper for them to record their answers. The rest of the questions will be asked verbally in a small focus groups)
3. What do you think of using Learning by Questions in lessons?
4. Do you like this kind of mathematics work? What do you like about it? Please explain.
5. Could you name one of your favourite activities that you completed recently in mathematics using LbQ?
6. Were there any maths activities you did not like on LbQ? Why?
7. Have you had any problems with the laptops or the LbQ site? Which ones? How did you solve it?
8. How difficult or easy did you find the quizzes that your teacher set for you using LbQ?
9. Did you find it easier or harder to answer the quizzes on LbQ compared to the maths quizzes or tests that you did before the project?
10. How do you know if you understand a topic well in mathematics? Did LbQ help you to understand this? If so, how?
11. How easy is it to get help if you have not understood something? Has this been any different or is it the same after using LbQ? Please describe.
12. Which maths lessons do you prefer, the ones you have had this term or the ones in the previous term and before? Why?



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