Why technology has failed to raise educational attainment

and how DoodleMaths solves the problem

By Tom Minor and Nicola Chilman, co-founders of DoodleMaths January 2017

Technology *has* impacted education... but not in terms of attainment

When it comes to educational attainment, the transformational change that technology was going to bring about is still waiting in the wings. There's no doubt technology has been effective in making time efficiencies, in progress-tracking, and increasingly in home-school communication. But in terms of attainment? Not a bit. Take the three biggest investors in

EdTech in the last 10 years: the US, the UK and Australia. Now look at their steady decline in their PISA rankings for maths:

Year of PISA Test	US Score	UK Score	Aus Score
2006	474	495	520
2009	487 (+13)	492 (-3)	514 (-6)
2012	481 (-6)	494 (+2)	504 (-10)
2015	470 (-11)	492 (-2)	494 (-10)

These countries, with the highest access to technology in the classroom in the last 10 years, all show steadily declining scores. Here are two other notable studies that have reached similar or inconclusive findings:

2.5 Million Laptops Later, One Laptop Per Child Doesn't Improve Test Scores (Inter-American Development Bank)

The Impact of Educational Technology on Student Achievement (John Schacter)

Looking at maths education in particular, there is no doubt that resources such as Omnigraph have successfully taught specific areas of the curriculum in a more engaging manner; that resources such as Mathletics have created excitement and competition in maths, especially those more able; and that resources such as MyMaths have saved countless teachers countless hours with their vast bank of web-based activities. But the evidence that they actually raise attainment is minimal.

What qualifies us to tackle this problem?

We are both teachers. After a combined 15 years in the classroom, in 2007 we opened up two Kip McGrath education centres in Bath, UK. The Kip McGrath method, in the right hands, is a very powerful method of raising attainment. We were also familiar with the Kumon system, so carefully constructed that it raises attainment even in the hands of non-specialists (most Kumon centres are run by 'instructors', not trained teachers). Both methods do not rely on 1-to-1 tuition, rather, they work by identifying a child's learning level (or their *Zone of Proximal Development* - see later on) and their strengths and weaknesses, and then

encouraging regular daily practice on carefully-authored questions that get gradually, almost imperceptibly harder as the child moves through the program. Our challenge was to replicate this process using technology.

A time of rapid technological change

We started developing DoodleMaths in 2012 - a time when the computer industry was undergoing rapid change.

At a hardware level, exponential improvements in processing speeds, working memory and data storage were leading to 'big data'. Wherever we go, whatever we do, data is collected about ourselves and our behaviour. Data is modern day currency for the big corporations such as Facebook, who in 2012 were obliged to reveal to one user (Max Schrems – Google him!) that they had amassed an incredible (but fairly typical) 1200 pages of data in relation to his usage of their website. It has become incredibly easy to collect data. I'll talk more about our use of big data further on.

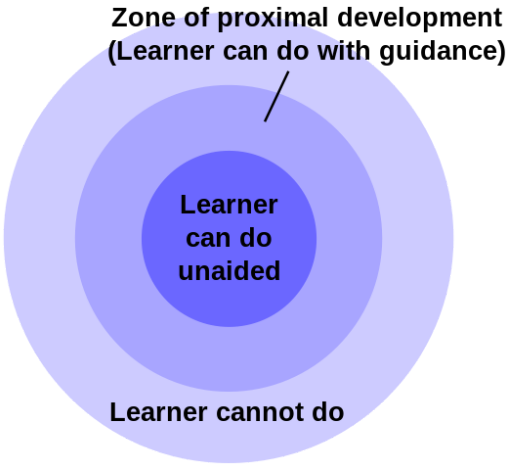
At a consumer level, people were making the switch from accessing the internet through Internet Explorer on a laptop at home to accessing it on tablets and smartphones using applications (apps). As more established competitors struggled to make their vast amounts of typically Flash, or video, or mouse/keyboard-based) content compatible, we were able to exploit the touch-screen to its full potential. "Trace the hexagon with your finger" is far more powerful than "Click the hexagon". A protractor that you can move and rotate with two fingers, and that snaps into place on the apex of the angle, is a far deeper learning experience that anything previously possible on a PC.

Finally, consumers were using web-browsers less and less - instead, they were accessing the internet through applications (apps). The instant appeal of educational apps is obvious. For example, DoodleMaths does not rely on an internet connection. This was an important aspect of our product design. Users make progress by using the app for a few minutes each day. It is unrealistic for this to be done at a desktop PC. Children can do their DoodleMaths on the school run, on the bus, the Underground, waiting for a sibling to finish their swimming

lesson, and so on. They can access their maths at the single touch of a button rather than waiting for a website to load. Apps deliver a far superior user experience to websites, allowing children to get started quickly and work through questions at a rapid rate. When it comes to use in schools, teachers are alerted should the app be closed, meaning 100% engagement. But most importantly, it allows us to exploit mobile technology, such as always-on and push-notifications, to help us build a habit-forming product.

The Zone of Proximal Development

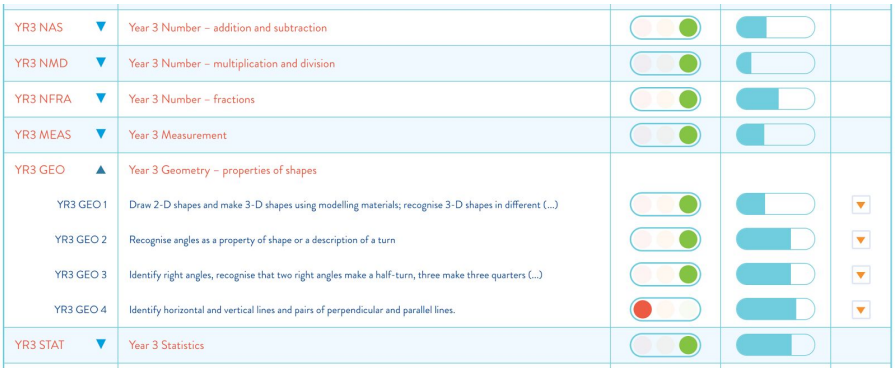
DoodleMaths was fortunate to be developed at a time that allowed us to exploit the new world of apps, and thus drive superior engagement with our product. But, as argued earlier, engagement alone does not equal progress. Children need to be regularly engaged in questions at the right level if they are to progress in their learning. This is what Kip McGrath and Kumon do so well using human interaction, but edtech generally does not.



To make meaningful progress with their learning, children need to be engaged in a work in their *Zone of Proximal Development* (ZPD). This is a concept first proposed by Russian psychologist Lev Vygotsky (1896–1934). Inside this zone, children will be practising what they already know. Beyond this zone, children may be able to follow a method in the short term, but they probably won't understand it sufficiently to ensure progress in the long run.

Existing edtech solutions rely on either children, parents or teachers to choose the content to be worked on. If you allow a child to choose, invariably they will select work that is well within their ZPD. When a teacher chooses, they select for a whole class or a group of students - they'll hit the ZPD for some but not others. If they do select work on an individual basis, it requires detailed knowledge of every class-member's strengths and weaknesses. Finally, if the parent chooses, invariably they are overwhelmed and do not have enough knowledge of the curriculum or their child's maths to do this accurately.

But, as previously mentioned, we live in the world of big data. Maths teachers love data, which has traditionally been collected through the marking of tests and homework, and more recently through technology. Now a fairly dynamic teacher might use such data to provide some support work, differentiate in the classroom, or select students for extra provision, for example. But generally, this data is used for reporting purposes only.



We share this data with the teacher, but more importantly, it is this data that drives the algorithms that select future content. Through the 7-a-day feature, DoodleMaths is constantly probing a child's strengths and weaknesses - initially all of the questions are diagnostic, and as a learning profile develops, that proportion decreases. A child is struggling with fractions equivalent to ¼ and ¾? Well, let's go back and recap fractions equivalent to ½ first. A child is struggling with their number bonds to 20? Let's recap bonds to 10, then try explaining bonds to 20 again. A child needs more consolidation calculating areas and perimeters? Let's build it into their program. DoodleMaths can make many such decisions on an individual basis that a teacher faced with any significant group size could not. These decision-making algorithms control the child's work program and are part of the key to DoodleMaths' success.

Children learn through doing

Children - and especially younger children - learn through doing, not watching. Many tech solutions still put emphasis on Flash animations, or lengthy video explanations, often lasting 5-10 minutes, teaching a concept from scratch. These full and thorough explanations are necessary with a group of children who are coming from different starting points, and when it is difficult to be sure they all have the necessary pre-requisite knowledge in place. But if you carefully grade a curriculum and put plenty of emphasis on retention of previously-learned

material, it is possible to reduce these explanations to a minimum. For example, it is much easier to teach equivalent fractions to ¼ if you are sure, through previously-collected data, that the child already understands equivalent fractions to ½. By having this knowledge, we are able to cut down on lengthy explanations (that often don't hold children's attention spans anyway, and give no opportunity for reward) and focus on teaching children through the act of doing - so they are learning by answering questions and engaging with the subject matter. Some significant research went into DoodleMaths to most effectively do this, as outlined below.

Questioning techniques

A good teacher will be asking themselves, as they write a maths exercise, "What is the purpose of this question?" There are many types of maths questions - for example:

1. Questions that teach
2. Questions that reinforce understanding
3. Questions that extend and deepen understanding
4. Questions that test understanding
5. Questions that generate discussion

Questions that teach are rare. This is because they are difficult to write, and traditionally, teachers have done the teaching. Such questions ask children to have a go, to experiment. Children like doing these types of questions. They also don't mind getting them wrong. Often, these questions are inductive questions (see later on.)

Questions that reinforce are very common. These are easy to write and extremely important when it comes to long-term understanding. Children like doing these questions – as long as they are getting them right.

Questions that test are, for many teachers, favoured questions to write. They are more interesting to write and help a teacher assess the ability of a child. For this reason they are often overused – sometimes with damaging consequences: if introduced too early they can damage a child's confidence. Some children (the brighter ones) can thrive on these

questions, but for others, these questions lead them to a dread of maths, undermining their confidence and sense of achievement.

Questions that generate discussion are created by skilled teachers who have the ability to control the direction of the ensuing discussion to reach the desired learning outcome. All children like participating in these discussions as long as it is conducted appropriately.

Before the advent of ICT, the learning process was typically: teacher teaches; child does questions of type 2 and 3; teacher marks questions to gauge level of understanding.

Tutoring websites have tried to replicate this with: video/animation teaches; child does questions of type 2 and 3; website marks questions to gauge level of understanding.

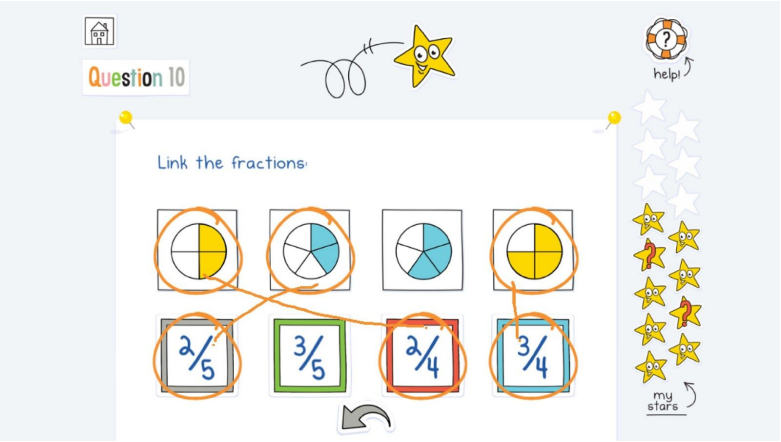
So far, we have missed the huge teaching opportunity that technology has presented to us: to get children involved in the learning process from step one. It is easy to create inductive questions (that teach) on the iPad, and children love doing them – this is the way children should be learning and this is the system of learning which has been developed for DoodleMaths.

Inductive learning

Inductive learning is defined as allowing students to "generate their own information, organize that information, make sense of what they have collected, and communicate their understanding to others" (Dell'Olio & Donk, 2007). It is the most powerful way for children, and especially young children, to learn things for themselves.

DoodleMaths employs this technique a great deal, especially when introducing a new topic, in the form of sorting, linking and ordering questions. These questions, alongside more traditional questions, engage the user from a very early stage and move them quickly to a point of understanding through their own experimentation.

Many of the inductive questions you will see in DoodleMaths have pre-determined outcomes. For example, we might ask children to link fractions to their diagrammatic representations, thereby allowing them to determine that the top number represents how



many parts shaded, and the bottom number represents how many parts in total. Of course, sometimes a small amount of teaching may also be required too, but the child is involved from step one.

Let's be clear: most children don't like to learn by sitting, watching and listening to teacher, a video, or a cartoon animation when they could be doing it for themselves. This is a principle we have applied throughout the DoodleMaths learning system.

The importance of reviewing/revisiting prior learning

In schools, maths is largely taught in topics. Students learn percentages, then perhaps move on to equations and then on to probability or some other topic. Maths has always been taught like this, so what's the problem?

There are two problems: first, by the time you are 15, you don't want to be learning percentages for the fifth time, knowing you'll forget it in a couple of weeks; second, teaching in this way can often make maths seem like a series of discrete (rather than interconnecting) range of topics.

Of course, the brightest students, to whom maths comes easily, will remember from year to year how to do each topic. They will see links between topics for themselves, and will continue progressing towards a top grade. But for the substantial majority of students, where their only goal is a GCSE pass, they forget what they have learnt pretty rapidly.

The solution is to give students the opportunity to review what they have learnt, as well as to learn the new. Between 75 and 86% of a child's DoodleMaths work program is about consolidation. Students continually review prior learning in order to ensure that this

knowledge is secure, providing a solid foundation for future learning. It is also a key opportunity for us to analyse performance in order to determine what comes next.

The power of little and often

Review is best done on a daily basis. We know of countless children who have piano lessons every week. The ones who move through the grades aren't the ones who have the best teachers. It's not necessarily even the most gifted. It's the ones who put in their daily practice.

Maths is no different. We can tinker with the Framework and the National Strategy; we can try to employ the best graduates as teachers. But the simplest way to raise standards in maths would be to give children more opportunities to exercise the left side of their brain.

We're not the only ones who favour a little-and-often approach to teaching maths. In fact, part of the inspiration for DoodleMaths was the "-a day" series of books written by A.L. Griffiths in the 1970's. The previously-mentioned Kumon method also favours this approach.

Of course, technology has made a huge difference, not just in how these questions are delivered, but also to how they are chosen. When a child selects 7/8/9/10-a-day on DoodleMaths, their set of questions are chosen according to the following criteria:

1. to reinforce topics that have been recently learnt
2. to reinforce topic areas that the individual needs further practice in
3. to review prerequisites to up-coming new topics to be learnt
4. to help identify other weak areas.

This means that in the DoodleMaths learning system no two children will receive the same set of questions - creating a unique user experience.

Engaging our users

It has long been a problem with existing maths IT resources that usage drops off after an initial 'honeymoon' period. The enthusiasm for the new resource wanes over time for a number of reasons:

1. The resource loses its newness
2. If it is a competitive resource, it's often the usual members of the class who dominate leaderboards and are most successful
3. No work has been set for the child to complete
4. There's no sense of progression
5. There are no incentives for completing the work
6. The product is not habit-forming

We have sought to address many of the issues above. Crucial is the fact that DoodleMaths questions are carefully selected according to the child's ability, previously learnt concepts, and concepts that require more reinforcement. This allows us to ensure each question is pitched at exactly the right level to give the user a sufficiently challenging and motivating experience. This tackles many of the issues above: because every child is challenged at their own individual level, it gives every child the chance to be top of the leaderboard in their class for questions answered, and it is common to see children who are not normally associated with success in maths rapidly gaining in confidence. There is always work available for the child as we are not relying on human input to construct the work program. We encourage usage little-and-often, and since DoodleMaths is built for mobile, this is easily done. We are using techniques more commonly associated with social apps such as Facebook, Twitter and Pinterest to encourage and incentivise children to open the app on a daily basis with the aim of it becoming a daily habit.

DoodleMaths also offers engagement through other methods - principally the combination of avatars, rewards and games. All users select an avatar which regularly appears with words

of encouragement. High levels of effort keep avatars healthy, and are also rewarded with DoodleStars which can be spent on avatar accessories.

Measuring success

Success is defined in different ways by different end-users of DoodleMaths. Children want to feel a sense of progression and feel credited by their teachers, parents and peers. Parents want to see a child become more confident in a subject that children have previously been anxious about. And teachers and schools want to see a raising of standards.

Ultimately, though, our mission is to raise levels of attainment in maths by supplementing (note *not* replacing) the good work already taking place in the classroom. With this in mind, two small-scale studies were conducted during the development of the product, at a local primary school and a local secondary school. Both these studies, involving six children and nine children respectively, showed that 15 minutes of DoodleMaths daily over the course of 4 weeks improved their independently-measured maths age by 3.5 months. More recently, the University of Bath conducted a large-scale study involving 128 children throughout July and August, and discovered that just 20 minutes usage per week meant children were four times less likely to suffer from summer learning loss. These gains are hugely significant and far exceed any studies conducted by competitor products. Furthermore, they are replicable, since our algorithms choose the content on a wholly consistent way - progress made using competitor products depends largely on the teacher setting appropriate content - something which is not at all consistent as some do this better than others.

We continue to work with the University of Bath to gain a greater insight into what aspects of DoodleMaths accelerate attainment most rapidly to help inform future product development. DoodleMaths (and in fact any learning system) will never replace a good teacher. But used as a resource to deliver a personalised maths experience as part of a wider program, it delivers phenomenal results.