Learning basic Algebra by playing 1.5h

What the 40 000 students who participated in the DragonBox Algebra Challenges demonstrate

Objective and methods of the DragonBox Algebra Challenges

Educational games creators at WeWantToKnow, and scientists from the Center for Game Science at the University of Washington have partnered to conduct an experiment in order to answer the following question:

Can all K-12 students master basic algebra with game-based learning, in a short time?

Large scale week-long events called “Algebra Challenges” have been conducted in Washington State[1] and Norway[2]. 40 302 students participated in these challenges, and played an adaptive[3] version of DragonBox Algebra 5+, with their classmates and teachers.

DragonBox Algebra is a game designed specifically to teach algebra. It presents the player with whimsical icons that must be manipulated until the ‘Dragonbox’, representing the unknown variable, is isolated on one side of the game board. Players might not realize that they are learning algebra at first, but they are already learning basics such as balancing an equation. Through the course of play, these icons are gradually replaced with numbers and variables until the player is solving real equations. The rules of variable manipulation are discovered through experimentation, and higher star ratings are obtained by manipulating variables more efficiently to isolate the ‘box’ in fewer steps, ie simplifying the equation with an optimal strategy.

Using the adaptive version of DragonBox Algebra developed by the Center for Game Science, students in each Algebra Challenge had a collective goal: solve hundreds of thousands of equations. Students played at school, with their classmates and teachers, as part of their regular school time. They also had the possibility to access their game account at home if they wanted to play more.

This study presents the preliminary results from the first 2 Algebra Challenge experiments and discusses the profound impact adaptive game-based learning had for each student. This study has been prepared independently by WeWantToKnow, using data and analysis provided by the Center for Game Science.

1: http://wa.algebrachallenge.org/
2: http://no.algebrachallenge.org/
3: Adaptive means that the game detects how each student is performing, and tailors the learning progression to the specific needs of each individual.

Foreword

Jean-Baptiste Huynh
CEO of We Want To Know

How could many of our kids, who have mastered the complex rules of language, somehow be unable to learn the much simpler rules of algebra? Either mathematics suddenly makes them dumb, or we must accept that they are very much able to learn maths, but that our teaching methods just don't work well enough. As a teacher and a father with kids in school, I find this very hard to live with. The good news is, I don't have to accept this state of affairs: game-based learning is an extremely powerful learning method, and this report shows the huge impact educational games can have today.

When I started researching pedagogy and designing learning experiences, video games quickly became the obvious choice if I wanted to bring about real change in learning. Games are uniquely suited to the way we learn: in a game, the reward we want for mastering a challenge is getting to the next challenge, and we're learning new tricks each step of the way. What's more, games provide precise and immediate feedback. On top of this, levels in a game can be designed to act as formative assessments, allowing teachers to know exactly how their students are learning and where they need extra help.

With this in mind, with my co-founders and our team at WeWantToKnow, I created DragonBox Algebra, our first game. It received accolades from parents and educators alike, and even got the attention of the White House. We decided we needed structured research to provide scientific evidence for the great things that were being said about our game. We partnered with the Center for Game Science at the University of Washington to create an adaptive version of DragonBox Algebra, and we devised large-scale experimental learning events: the Algebra Challenges. **These are a new type of learning method, bringing together usage and resource, for which we propose the term MILE (Massive Interactive Learning Event)**.

Back to the first Algebra Challenge, as soon it launched, teachers registered their classes to participate, and students started playing and solving millions of equations. The results speak for themselves: 93% of students who played at least one hour and a half reached mastery of basic algebra!

The data in this study proves that we can change the way Algebra is learned, and the methods used can be used for many other subjects. We are now on our way to proving just that by tackling geometry with the release of DragonBox Elements. This new game teaches Geometry through Euclidian proofs, by actually getting its players to recreate the very mathematical proofs that are the foundations of geometry. We hope DragonBox Elements will prove to be as transformational for geometry as DragonBox Algebra has been for learning to solve equations.

However, no matter our results with Algebra or our ambition with Geometry, we are just one startup, partnering with just one scientific team. If there is to be real change in education, we need more game creators, scientists, and educators to create innovative learning games and methods. We also need decision-makers in education to support wholeheartedly this educational revolution. This is a call to arms: we are entering a new era, where game-based learning, big data, and adaptive algorithms will bring about a huge leap forward in education. Teachers want it, students need it, the technology is here, there is no reason to wait any longer.

KEY FIGURES & TAKEAWAYS

1) 93% of kids who played at least one hour and a half learned basic Algebra

93% of all students who played at least 1.5h learned successfully how to solve basic equation, when traditional methods require dozens of hours, with lower final success rates.

2) A large majority of 3rd graders can learn Algebra

80% of 3rd graders on average can learn what is usually considered material for late middle school (8th grade) and high school, with much improved success rates.

3) (Really) no child left behind

Pupils who can't learn with the average amount of material available are usually left behind, as we discovered they require on average 5 times more educational material to learn, and teachers can't simultaneously teach each student individually. Adaptive learning allows each student to access specifically the material they need, when they need it.

4) Homework happens naturally

In Norway, 43% of the play/learning time was at home, with the students choosing to play without being assigned homework. Motivation is key in learning, especially for students who need to spend more time learning a given subject that their classmates. In Norway, media coverage helped project a "cool" image for the MILE (Massive Interactive Learning Event), making learning algebra cool by association.

5) Built-in formative assessments

Formative assessments are essential to an efficient learning process, and are built into the game. Adaptivity means that each assessment is directly used to provide the learner with an adequate learning progression. 471,714 formative assessments were administered during the DragonBox Algebra Challenge in Norway.

Important definitions:

In this study, two levels of mastery are distinguished. When used in this document, the term mastery indicates the first level of mastery, labelled "Mastery" in the graph. Additional learning resources to transfer game mastery to pen and paper mastery are offered to teachers.

Mastery means that a student can solve equations such as: x*a/d+ b = c/e
Hard mastery means that a student can solve equations such as: a/cx + b/x = d

DETAILED ANALYSIS

1. 93% of kids who played one hour and a half learned basic Algebra

Students spend dozens of hours, both in class and at home, learning the basic rules and properties of Algebra with the traditional curriculum. Regrettably, many of them actually fail to learn algebra with traditional methods. By comparison, students participating in the Algebra Challenges learned in a much greater proportion and in much shorter times.

What this study shows for Algebra can be extrapolated for other subjects, both in mathematics and in other areas of study. As this report is being compiled, WeWantToKnow is preparing to release DragonBox Elements[1], a game that aims at showing that geometry can be learned much faster as well, using a game-based method. The method used in DragonBox Elements is inspired by the foundational work of the Greek Mathematician Euclid, who wrote the 13 volumes of "Elements" 23 centuries ago, a text that is still a reference today.

Key findings

Across all grades, a huge majority (93%) of the children who played at least 1.5 hours reached mastery. What's more, the chance to reach mastery keeps on improving with playtime, with mastery levels reaching 97% for students who played an extra half hour. (Graph 1.A)

In high school, students reached mastery by playing 80 levels on average, while 1st and 2nd graders reached mastery by playing 120 levels on average. (Graph 1.B)

The chances of success improves steadily with the number of equations played: 88.5% of students who played at least 100 levels reached mastery, while 98.5% of students who played at least 300 levels reached mastery (graph 1.C)

1: DragonBox Elements, http://wewanttoknow.com/elements

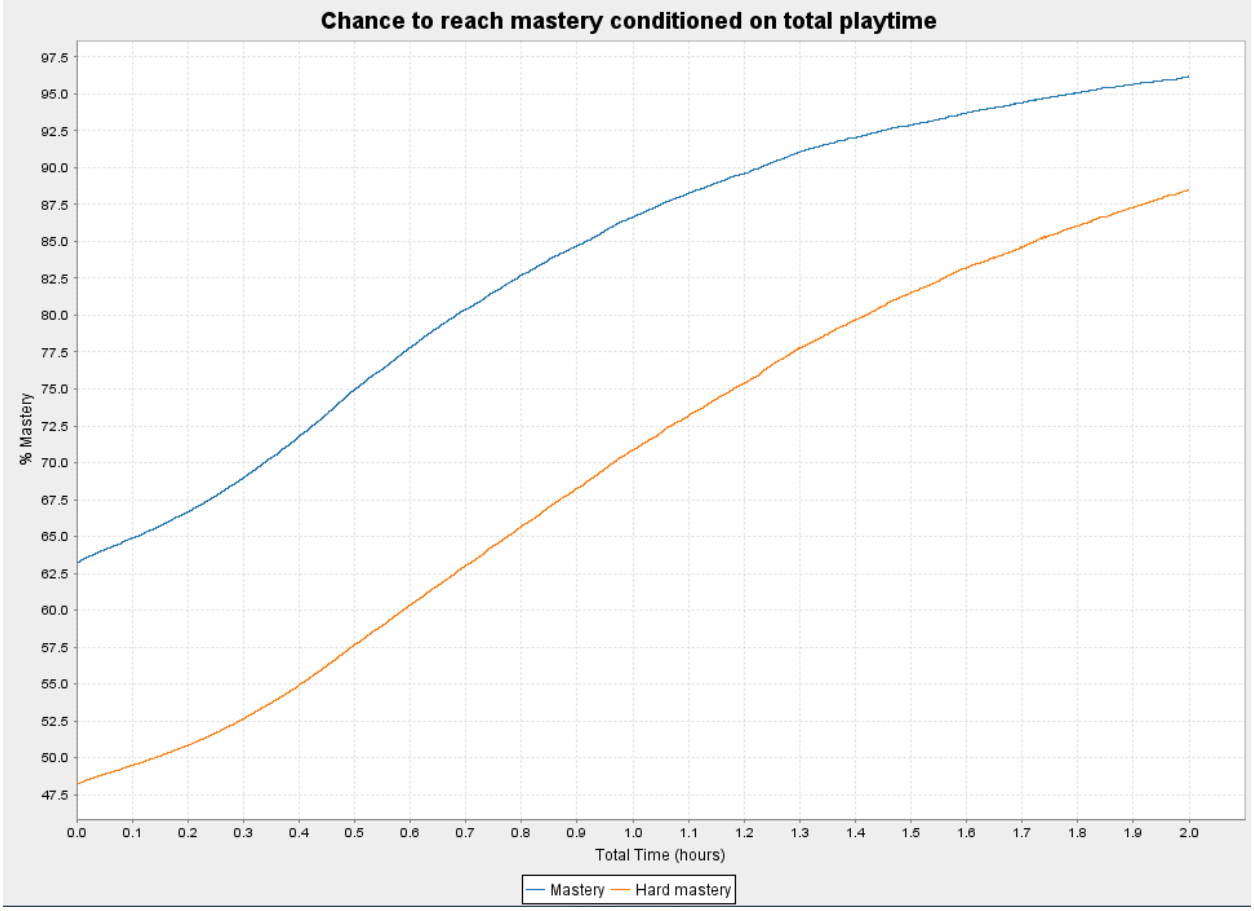
Graph 1.A

The following graph shows the chance of achieving mastery depending on duration of play, for the whole group of participating students, from 1st grade to high school. **The longer a students plays, the higher the chance they will achieve mastery.**

Key stats

Among students who played at least 1.5 hours:
- 93% reached mastery
- 81.5% reached hard mastery

When looking at students who played at least 2 hours, these numbers climbed even higher:
- 97% of students reached mastery
- 88% of students reached hard mastery

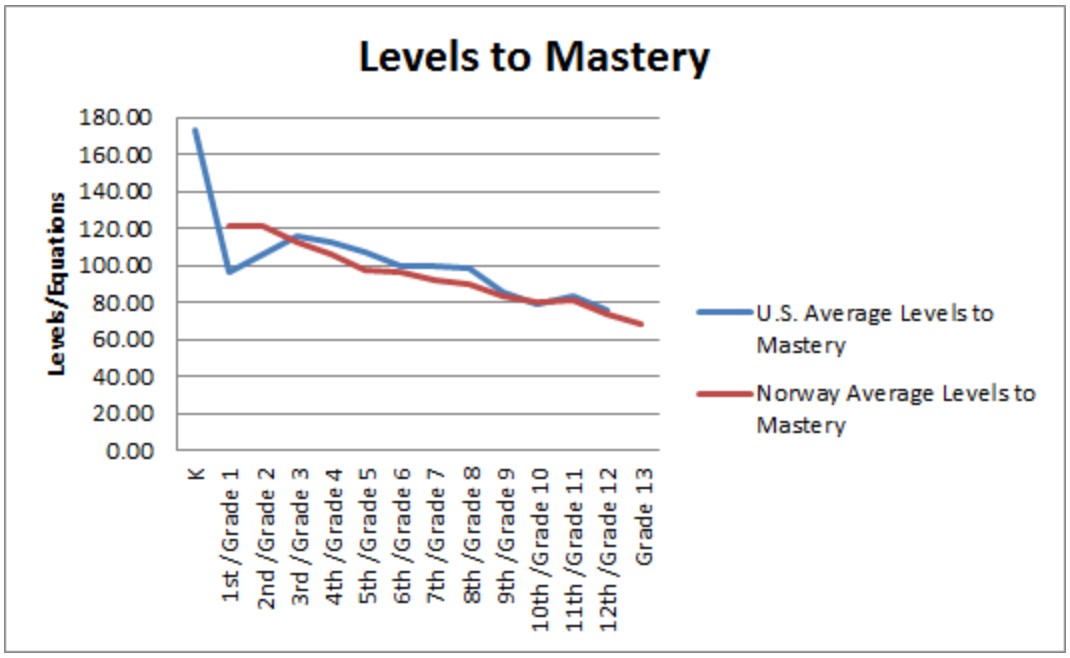


Graph 1.B

This graph shows how many levels were played on average before reaching mastery, for each age class. Elementary school children need to play only 50% more equations than high school students to reach mastery.

Key stats

- In elementary school (grade 1-5), students played 100 to 120 levels on average before reaching mastery.
- In middle school and high school, students learned faster, playing from 100 levels to mastery on average in 6th grade, down to 80 levels in high school
- Learning patterns appear very similar between US students and Norwegian students (NOTE: extra data is needed before we can conclude anything on the divergence in 1st and 2nd grade between Norway and the US).

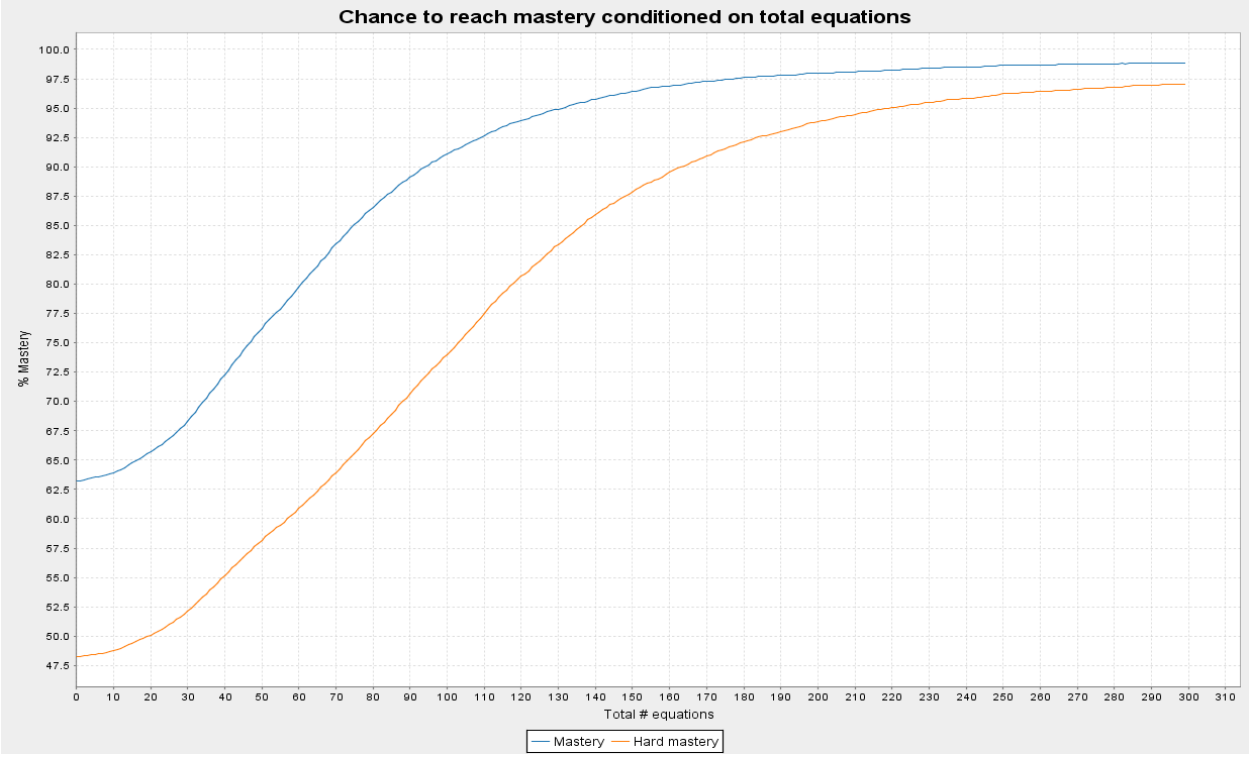


Graph 1.C

This graph shows the evolution of the chance of reaching mastery, depending on the number of equations played, for all students in the Algebra Challenges.

Key stats

- Chance of reaching mastery, for students who played at least 100 equations: 88.5%
- Chance of reaching mastery, for students who played at least 200 equations: 97.5%
- Chance of reaching mastery, for students who played at least 300 equations: 98.5%



2) A large majority of 3rd graders can learn algebra

In most countries, Algebra is taught either at middle school or high school level. In the US, Algebra is often considered a "gatekeeper" course, and failure rates can reach 40 to 50%[1]. A large number of students therefore never learns Algebra properly, and many actually develop an active repulsion for it, and often for maths in general.

On the other hand, a recent paper[2] published in Developmental Science shows that preschoolers aged 4-6 can actually perform very basic algebra using their innate ability to estimate numbers and quantities (Approximate Number System). This converges with the empirical evidence gathered from DragonBox Algebra 5+, in which children from 5 years upwards, and sometimes even younger, have demonstrated their ability to solve an equation for x, using non-mathematical symbols at first (manipulatives), before transitioning smoothly to mathematical symbols.

Key findings

From 3rd grade, over 80% of children achieved mastery of basic algebra. This is a full 5 years before the level at which they usually learn the subject in a traditional curriculum. (Graph 2.A)

The proportion achieving mastery climbs to 90% and above from 5th grade. (Graph 2.A)

1: Laura Pappano. **The Problem with Algebra**. Harvard Education Letter, Volume 28, Number 3, 2012; http://hepg.org/hel-home/issues/28_3/helarticle/the-algebra-problem_533
2: Melissa M. Kibbe, Lisa Feigenson. **Young children 'solve forx' using the Approximate Number System**. Developmental Science, 2014; http://onlinelibrary.wiley.com/doi/10.1111/desc.12177/abstract;jsessionid=3489BA2D93593DAA187CF50B7DE9F42D.f02t02

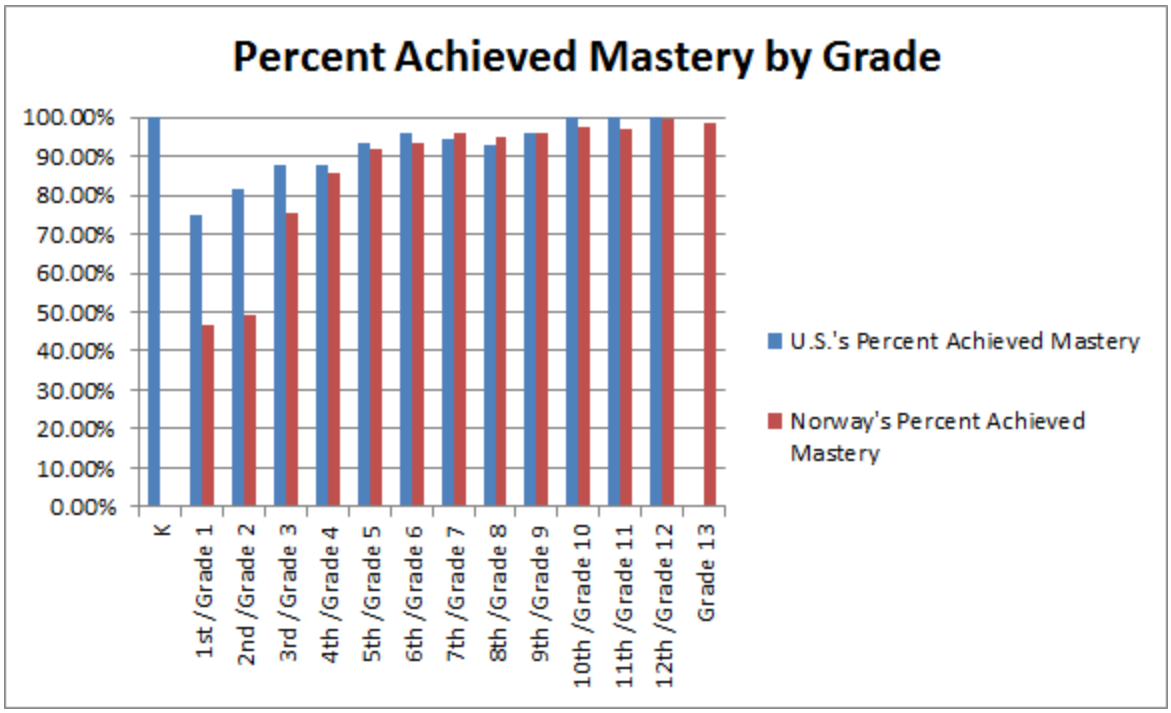
Graph 2.A

This graph shows the proportion of students achieving mastery in each grade.

Key stats

- From 3rd grade, over 80% of students have achieved mastery
- This proportion climbs to 90% from 5th grade onwards

NOTE: This graph includes data for US 2nd graders, 1st graders, and even a few kindergartners. No conclusions should however be drawn at this point however, as additional data from different regions and countries is necessary to explain the important variation that can be observed in the graph.



3) (Really) no child left behind

In most educational systems, teachers are given an impossible task. They teach for a heterogenous group of students, and yet they must simultaneously:

- *Get their class as a whole to score high enough when they are evaluated against standardized learning milestones*
- *Make sure the least proficient of their students don't get discouraged and abandon*
- *Make sure the most proficient of their students don't just get bored and stagnate*
- *Make sure their teaching addresses in priority the needs of the majority of their class, by definition somewhere around the average*
- *Do all this with a limited amount of time and resources, and no powers of ubiquity*

One of the goals of WeWantToKnow and the Center for Game Science is to create methods and tools with which teachers are empowered to actually deliver the kind of individualized teaching they seek to provide, along with contextualized cues and immediate feedback[1], so that students can each learn in a way that is uniquely optimized for them. The Center for Game Science has worked in partnership with WeWantToKnow, on creating an adaptive version of DragonBox Algebra 5+. This adaptive version detects how each student is performing, tailors the learning progression to the specific needs of each individual, and generates the exact type and amount of extra content needed by students who have trouble mastering a given concept.

Key Findings

To reach mastery, the bottom percentile of students needs to play through 5 times more material on average than top percentile in their class, and 2 to 3 times more material than the 50th percentile in their class. (Graph 3.A)

The top percentile of students learns 2 to 3 times faster than the average of their class. (Graph 3.A)

While the spread between the top and bottom percentile remains similar from grade to grade, the spread between more average students (10th, 50th, 90th percentiles) narrows as students get to later grades. (Graph 3.A)

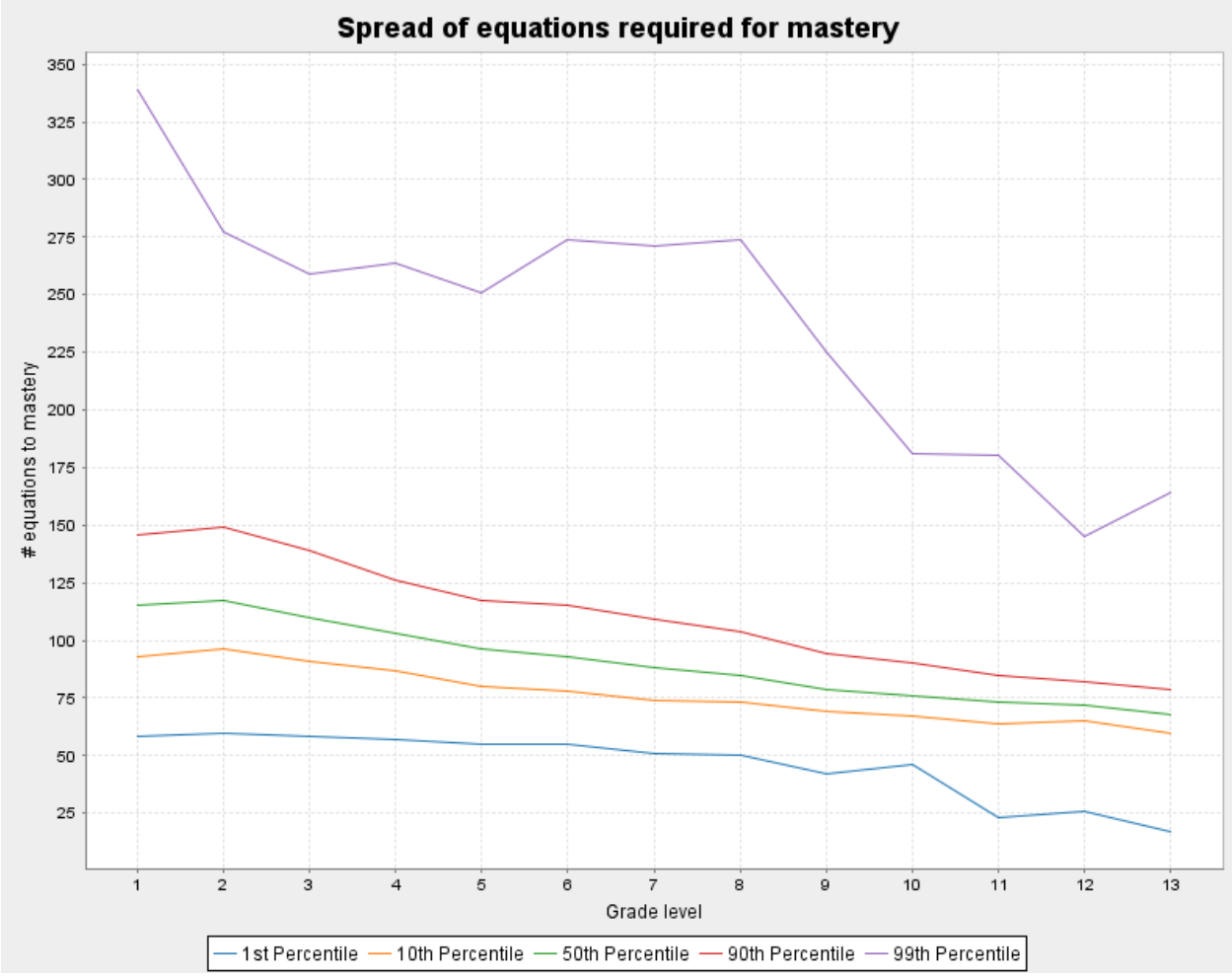
1: John Hattie and Helen Timperley. **The Power of Feedback.** REVIEW OF EDUCATIONAL RESEARCH 2007; http://education.qld.gov.au/staff/development/performance/resources/readings/power-feedback.pdf

Graph 3.A

This graph shows the number of equations needed to reach mastery for key percentiles in each grade.

Key stats

- The top percentile of students can reach mastery in 58 equations in first grade, and 25 in 11th grade
- The 50th percentile of students can reach mastery in 120 equations in first grade, and 75 in 11th grade
- The bottom percentile requires 335 equations to reach mastery in first grade, and 180 in 11th grade.



4) Homework happens naturally

Norway is the biggest of the Algebra Challenges organized to date. 36110 students entered the challenge, from 1st graders to students in the last year of high school. The Norwegian Algebra Challenge received widespread media coverage in Norway (print, tv, and web) as well as dozens of daily mentions on social media sites.

The Algebra Challenge projected a "cool" image through this coverage, and students responded by showing very high levels of engagement in the event (a little over twice as much as in Washington State). Student teams really got into this country-wide competition, devising strategies and achieving sometimes impossible results. While equations solved in impossibly short times (under 2 seconds) were disqualified for cheating, the very fact that students could become so engrossed about a game that teaches Algebra at its core, is an achievement in itself.

Key findings

Students played for a great deal of time outside regular school hours (43.9 % of total time - graph 4.A)

The Algebra Challenge and its media coverage created the perception that Algebra is something cool for Norwegian students, which heightened engagement.

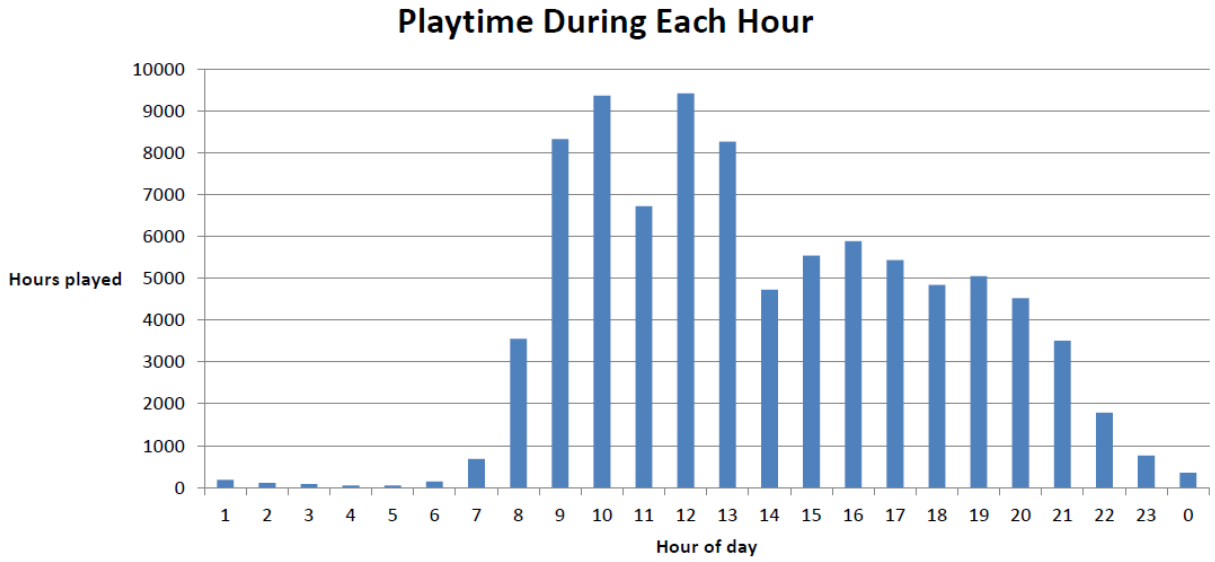
Motivation to play longer, and to play more equations allows students to improve their chance of mastering algebra. (graphs 1.A and 1.C).

Graph 4.A

This graph shows the total amount of hours played by students, for each 1-hour slice of the day.

Key stats

- 43.9% of total playtime occurred outside of school time
- Hours of playtime were recorded even in the very middle of the night



5) Built-in formative assessments

DragonBox Algebra is designed with 2 axis of progression. From level to level, players are introduced to new concepts. In each level, up to three stars can be earned, depending on the skill with which the player solved the equation in that level, ie whether the equation was simplified completely and in the lowest possible number of operations. This allows teachers to see the learning progression and potential difficulties with pinpoint accuracy for each student in their class, and for their class as a whole.

The adaptive version of DragonBox Algebra used in the Algebra Challenges furthermore helps the progression by adapting the concepts in each level in real time, depending on the performance of the player in previous levels. This is the very definition of formative assessments, which are assessments that are used to adapt the teaching to the needs of the students, and are essential in improving learning[1]. Thanks to continuous formative assessments, the adaptive version of DragonBox Algebra creates an optimal learning path for each student based on their strengths and weaknesses, assessing each level and generating the next step of the lesson accordingly.

In this manner, formative assessments are part of both the game and the learning process, and are actually fun. Teachers can see how each of their student progresses without interrupting either their play or their learning.

Key Findings

Game-based formative assessments allowed for both large amounts of very precise learning data to be gathered, and for students to play and learn uninterrupted.

Embedded tests allowed for formative assessment that was fun. 471,714 assessment tests were administered during the 5 day challenge in Norway.

1: Paul Black and Dylan Wiliam. **Inside the Black Box: Raising Standards Through Classroom Assessment**. PDK International, October 1998; http://academic.sun.ac.za/mathed/174/formassess.pdf

Special Thanks

We would like to thank **Zoran Popovic** and the entire team at the **Center For Game Science**, Washington University, for the amazing work they did on making DragonBox Adaptive. This is only the beginning, and we hope we will achieve even more together in the months and years to come!

We would like to thank the hundreds of **teachers, educators, and government officials**, in the US and Norway, for their willingness to innovate and for their support of the Algebra Challenges.

We would like to thank the tens of thousands of **parents** who understood that the video game their children were playing was truly educational, and who encouraged them along the way.

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