JUMP MATH AND THE RISK MANAGEMENT OF EDUCATION

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Abstract: *In this article we discuss the success of the program JUMP MATH in primary and secondary school in search for a system of teaching that produces similar results in all school levels of mathematics and possibly in the sciences. We view the program from risk management point of view and from algorithmic perspective. We propose a general frame of teaching mathematics that can be applied from schools to university level with great economic effect if the results are similar like the results of JUMP MATH*

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1. Introduction

Education in mathematics is of critical importance for economic development [OECD, 2010] but is largely neglected in countries as Bulgaria, but even in USA, which are below average in pre-high school and high school math according to PISA [OECD, 201]. Worse than that, "*the trend data show no significant changes in these performances over time*" three years after the initiative "Race to the Top" declared by President Obama. The problem of **management by slogans** according to Deming is that a stable system needs innovations to achieve significant change and problem solving is not enough [Deming, 2000]. Education in mathematics is both important and underdeveloped which makes it a priority topic for research.

The problems in American education system and policy are noticed many years ago by Feynman who was employed to assess school textbooks in mathematics and noticed both the poor quality of most of the books and the conflicts of interests displayed by those who are supposed to judge them and have their own textbooks in the competition. He goes as far as to blame the entire field of pedagogy as "false science" for its lack of significant results despite of decades of new theories and their applications to students [Feynman and Leighton, 1997].

Despite lack of progress in teaching mathematics on national level, the problem is not unsolvable. Thanks to some recent advances in cognitive science we know better:

- We know how important is systematic practice in acquisition of expert performance [Ericsson et al, 1993]. It is more important that genetic factors and IQ for long term success in a given field (IQ is not very strong predictor)
- We know that everyone is born with the ability to learn school math [Willingham, 2010]
- We know that is possible to increase fluid intelligence [Buschkuehl and Jaeggi, 2010]
- We know more about social dynamics and what causes the "Mathew effect" in education – rich-get-richer, poor-get-poorer or the dependence of success on the initial condition – the early school success which translates to later stages and the early failure that persists [Stanovich, 1986].
- We know what works and what doesn't with respect to rewards and punishment, intrinsic rewards and extrinsic rewards in learning, that is – the high cost of extrinsic rewards and the learning as its own prize [Willingham, 2008].
- We know that there are systems that work significantly better than current systems in many Europeans countries, USA and Canada, both from the consistent high ranking in PISA of East Asian countries and regions and from the success of JUMP Math.

Our current knowledge is enough to suggest a general framework for teaching science and mathematics that extends beyond primary school and the first year of secondary school, by analyzing the algorithms that work to provide the results of JUMP Math. First we will introduce some notions from dynamic systems and probability to explain the current state of affairs and define risks in teaching mathematics. Second we introduce this system of education Jump Math and analyze the core principles and algorithms. Third, we propose a general framework for teaching mathematics following those algorithms.

2. Positive feedbacks and risks in education

The Mathew effect is the high level of dependence of success on the initial conditions for it, or the success in education as disproportionately strongly related to early success. Kids who have early success tend to achieve more in later stages of learning that those who don't. Educated get more educated, the non-educated stay non-educated. In control theory, this mechanism is called "positive feedback" and describes a multiplicative process, such as economic growth in which increasing the output of the system feeds back to the production additively. The student is a dynamical system in which knowledge leads to more knowledge and lack of knowledge is a barrier of acquiring more of it. This is especially true in mathematics in which we have chain dependence of concepts and problems and the lack of knowledge in any part of that chain affects performance from that level on without limitation in the general case - something not-well learned in 1st grade can have effect up to high school [ECS, 2013].

Other than the hierarchical structure of knowledge in mathematics [Barnard, 1996] there is another mechanism that generates positive feedback – the **adaptive nature** of students. When a student fails a task he adapts to that disturbance by accepting a new reference level for his/hers ability, he/she erodes his/hers expectations to achieve on a lower level. The erosion of goals is common system archetype, studied in the field of system dynamics [Braun, 2007]. It leads to long term underachievement. This is especially valid if the student receives signals from the teacher that he/she fails because is incapable of success. If a student believes results are due to fixed traits that cannot be removed, it is less likely to put the same effort on the next problem which increases the probability of failure and a further lowering of expectations – a positive feedback that adds on the another positive feedback from the hierarchy of knowledge in mathematics (solving a problem depends on success in solving previous problems).

Positive feedbacks **increase variability** in a system – the kids who enter first grade have Gaussian distribution both in mathematical ability and in confidence.

If we accept confidence as a barrier for the second type of positive feedback, e.g. not estimating one's ability from failures or success, we can formulate it as the reverse of psychological sensitivity to failures or how easily a failure in a problem translates into lowered expectations and efforts. Due to the increased variability we observe negative system (intergroup) effect – increase of differences between students. Systems that deserve their name must decrease variability. Random distribution means there is no system – the Gaussian distribution on entering first grade is due to the work of multiple independent factor (kids coming from different social and hereditary background with different experiences). If the Gaussian distribution persists during the twelve grades, there is no system of education, there is no benefit of putting students in one room and teaching them under the same rules since they do not decrease variability of ability. Furthermore, variability increases which means we have anti-system and not system of education. The persistence of positive feedbacks and multiplying effects of learning is what limits our results and not inherent and immutable differences in students. As Fig.1 show, it is possible for a gifted teacher following JUMP Math to achieve complete transformation in one year and create a class of excellent students.

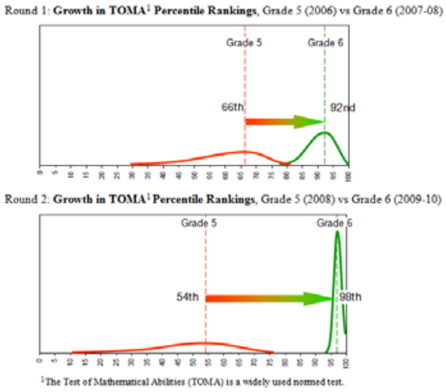

Fig.1 *The results one year education under Jump Math in Toronto, Ontario, Canada for two different classes – more on http://www.jumpmath.org/jump/en/research*

Other results confirmed in scientific research are – doubling the rate of learning in randomized trial [Solomon et.al, 2011]. There are also reports on the site of the program which show similar results, some of them for four consecutive years with one class - http://www.jumpmath.org/jump/en/research.

Similar improvements can also be achieved on national level, as PISA findings show for countries like Estonia and Finland [OECD, 2012]

Formulating risks:

- Risk of unfulfilled potential in math (very high): The main risk for any child in school is to be a victim of the negative part of the Mathew effect – to experience a chain of failures and to continue to lag behind successful children further with every year of education. The risk cannot be neglected even for naturally gifted children due to the high role of chance that these positive feedback mechanism supplies – it all depends on the first few years, of the first few problems and on the teacher who they meet first.

- Risk of underachievement in general education (high) – erosion of expectation transfers to any other field in which the student receives education. It is shown as a very high risk in reading and how it influences other activities, being the other fundament of education [Stanovitch, 1986]

- Risk of underachievement generally – erosion of expectations that leads to persistent low confidence which transfers in any activity in which the individual embarks – an extreme form of auto correction/adaptaion.

- Risk of **fragile knowledge** – a knowledge that consists of memorized techniques without understanding and leads to problems in applicability [Feynman and Leighton, 1997].

3. Managing risks in JUMP MATH

JUMP Math as a system of guided discovery is based on cognitive science and has a lot of different techniques that help educating every child even if he/she needs special attention. The textbooks for teachers are often 600 pages long or more. These vast amount of information may lead researchers and teachers to believe that this is just a random collections of techniques developed by several gifted teachers, but in fact the whole system can be explained by **few simple algorithms** that govern most of the content that has been created.

- **Divide and conquer** – Due to the individual differences of students for a given volume and/or complexity of a problem only a certain percentage of them will be able to solve it without help. To minimize that risk the problems are divided into sub problems and solved sequentially. If the complexity/volume of every sub problem is small enough, all students will solve it. This also minimize the risk of wasting time in rework with the students that fail.

- **Linear progression** – After a problem is solved, the next problem is incrementally harder in such step so every student to be able to solve it. As a rule several problems belonging to one complexity domain will be solved by just increasing visual complexity, for examples adding with increasing numbers without changing the algorithm, may it be finger counting or general. Each step is large enough to cause adaptation – increase of expectations and confidence, brain adaptation as a result of learning, but also small enough to be solvable for everyone. This also minimize both the risk of someone failing and the time, spent on a problem by the teacher. Students who are more advanced get harder problems in the same complexity domain to practice while the teacher is focusing attention on those who lag behind, which is related to the next algorithm.

- **Sequential learning of concepts** – a linear combination of previous two algorithms that takes care of the complexity of the material and allows only one new concept at a time to be introduced and then practiced enough so everyone can use it well before moving on next concept. Concepts evolve from simple to more complex instead of presenting the more complex and reducing from there. An example is the way fractions are taught – first geometric representation to form intuitive understanding, then actions with same denominators, then with different denominators, then to mixed fractions. Second sequence is by actions – from simple to more complex – addition before multiplication before division.

- **Recursive teaching** – Failures of some student to solve even sub-problems which are well divided is a sign of a missing link in the mathematical chain of knowledge. The teacher returns back on the material, with years if he/she has to until the place of breaking is identified. Then new set of problems is given to be practiced until success.

- **Network of concepts** – problems are solved using wide variety of techniques and different concepts (just like theorems can be proved fin many different ways). This helps students to form stable network of concepts and appreciate mathematics in depth, not just memorize algorithms of computation. Geometric representations, patterns and real world metaphors as well with other tools are used. This minimizes the risk of fragile knowledge and also help with increasing confidence through joy of understanding as complimentary of the joy of success.

- **Proactive control of confidence** – students are praised for their success and not critiqued of their failures, they are encouraged to develop the so called “growth mindset”. Evaluations and rankings are not accented to manage the risk of adaptation to them and to make differences persistent or increasing.

The results from careful and efficient applications of this algorithm is maximally increased knowledge for every student.

There is one more risk which is for the teachers, since there is similar variability and Gaussian distribution on certain metrics for them. Although it cannot be addressed the same way as the risks for the student, there are seminars for them and they have very specific and large textbooks to prepare their lessons. Due to the nature of the program, this variability translates into variability of results – from marginally better than other programs to complete transformation which is in itself a serious success. Other very important mechanism that decreases the variability is the adaptive nature of teachers. Teachers learn by teaching and having fast feedback from theirs students. A systematic approach to teaching students has a feedback that encourages systematic learning by the teachers.

4. Results of Discussion

High school mathematics and even university mathematics up to the level practiced by Fields medalist has the same hierarchical structure. Problems on every level can be divided and conquered (a main tool for mathematical research), teaching can be gradual, sequential and recursive. Praising and avoiding accent on ranking is still possible, although there are many of extrinsic awards for outstanding achievements made with good intentions that actually represent an obstacle and lead to Mathew effect in recognition of scientific achievement [Merton, 1968]. With increased complexity of mathematics the effort to make it understandable also increases in volume ass well the formed networks of concepts, but is still finite and thus we hypothesize that the goal is achievable. Thus, we propose to use those algorithms on every level of mathematics education by creating different content for every separate course that follows the principles which derive from them. A major part of such frame is usage of latest cognitive science research and constant revision and update of both content and methodology to reflect them.

- Usage of algorithms from JumpMath for gradual, sequential and recursive teaching.
- Emphasis on practice, deliberate and large in volume.
- Usage of intrinsic rewards, praise and proactive control of confidence of students
- Constant evolution and innovation in content and methodology in accordance to latest results from Cognitive science in cooperation with other teachers in the field that follow the same frame.
- Proactively requesting feedback from students - what is hard, why is hard, what is not understood for the higher levels of education.
- Starting students on research in University as early as possible. This is an extension of the guided discovery to the academic level.

5. Conclusion

It is widely accepted as “common sense” that some people achieve better success in school or expert status in some field due to inherent traits as IQ despite growing body of results showing the contrary [Ericsson et al, 1993]. Many people responsible for designing the systems and methods of education especially in some countries in Europe, USA and Canada believe this and accept the centered Gaussian distribution at the output of the system as normal in contradiction with systems theory. The success of countries like Finland and regions in East Asia where growth mindset is encouraged and variability in knowledge and skills is much lower as proof that this common sense is largely a myth. One promising system, originating from Canada – Jump Math is showing us how to transform education by using simple algorithms to manage risks. This is achieved by breaking negative system patterns like the Mathew effect and erosion of goals with the use of latest results from Cognitive Science. The core principles of this system are applicable to all level of mathematics because of its fractal nature, showing self-similarity in hierarchical structures on every level of complexity and abstraction. We propose general frame from which new content can be created for mathematics courses in high school and university and can be taught with similar (as we hope) result as the results of JUMP Math in primary school and first two years of secondary school. Mathematics is critical for economic success and should be the focus of systematic effort of policy makers in education with noticeable results in short time if risk management algorithms such as these in the proposed frame are applied.

6. References

[Barnard, 1996] Tony Barnard, Structure in mathematics and mathematical thinking. Mathematics Teaching No. 155, 6-10 (1996).

[Braun, 2007] Bill Braun. The Dynamics of the Eroding Goals Archetype, Proceedings of the 25th International Conference of the System Dynamics Society and 50th Anniversary Celebration July 29 – August 2, 2007, Boston

[Buschkuehl and Jaeggi, 2010] Buschkuehl M., Susanne M. Jaeggi,Improving intelligence: a literature review, Swiss Med Wkly 2010 ; 140(19–20):266–272

[Deming, 2000] Deming, William E, Out of the Crisis, MIT Press (200)

[ECS, 2013] ECS. Math in the Early Years. A Strong Predictor for Later School Success. The Progress of Education Reform. Vol. 14, ECS Policy Report (2013)

[Ericsson et al, 1993] Ericsson, K. Anders, Ralf Th. Krampe, and Clemens Tesch-Romer, The Role of Deliberate Practice in the Acquisition of Expert Performance, Psychological Review 1993, Vol. 100. No. 3, 363-406

[Feynman and Leighton, 1997] Feynman, Richard. P., Ralph Leighton, Surely You're Joking, Mr. Feynman! (Adventures of a Curious Character) W. W. Norton & Company; Reprint edition (April 17, 1997).

[Merton, 1968] Merton, Robert K.. The Matthew Effect in Science, Science, 159(3810):56-63, January 5, 1968

[OECD, 2010] The High Cost of Low Educational Performance, The Long-run Economic Impact of Improving PISA Outcomes, OECD, 25 Jan 2010, DOI: 10.1787/9789264077485-en

[OECD, 2012] PISA 2012 Results in Focus: What 15-year-olds know and what they can do with what they know https://www.oecd.org/pisa/keyfindings/pisa-2012-results-overview.pdf

[OECD, 2013], Lessons from PISA 2012 for the United States, Strong Performers and Successful Reformers in Education, OECD Publishing. http://dx.doi.org/10.1787/9789264207585-en

[Solomon et.al, 2011] Solomon, T., R. Martinussen, A. Dupuis, S. Gervan, P. Chaban, R. Tannock, B. Ferguson, (2011) Investigation of a Cognitive Science Based Approach to Mathematics Instruction, peer-reviewed data presented at the Society for Research in Child Development Biennial Meeting, Montreal, March 31 - April 2, 2011

[Stanovich, 1986] Stanovich, Keith, E,. "Matthew Effects in Reading: Some Consequences of Individual Differences in the Acquisition of Literacy", Reading Research Quarterly 21 (4): 360–407. doi:10.1598/rrq.21.4.1 (1986).

[Willingham, 2008] Willingham, Daniel T. Should Learning Be Its Own Reward? American Educator, winter 2007-2008

[Willingham, 2010] Willingham, Daniel T. Is it true that some people just can't learn math? American Educator, winter 2009-2010