Reasoning on Children's Cognitive Skills in an Informatics Contest: Findings and Discoveries from Finland, Lithuania, and Sweden

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Abstract. In this paper, we present the results from a multi-national study of students' results in the international IT contest "Bebras". Bebras provides motivating and game-like tasks in the format of multiple-choice questions and interactive problems to students in grades 2–12. Our study focuses on the results of nearly 8 000 students aged 10–13 in Finland (n=852), Sweden (n=201) and Lithuania (n=7 022), using gender, task and country as the underlying variables. In addition to presenting the overall results of the three student groups, we also analyse a subset of tasks in common according to Bloom's taxonomy and put forward detailed results for these tasks with regard to gender and country. The results show that there is no difference in performance between boys and girls in this age group. Our findings also indicate that there was a slight mismatch between the difficulty level of the tasks used in the contest and students' actual abilities; finding more efficient and trustworthy ways of evaluating difficulty levels upfront and choosing a suitable task set is hence important for upcoming contests.

Keywords: Informatics education, computer science education, computing education, competitions, "Bebras" contest, tasks, cognitive skills.

1 Introduction

The current status of informatics[1] education is unsatisfactory in many countries [12]. Although computers, applications and information technology (IT) in general is an increasingly natural part of the everyday work at schools, focus is mainly put on basic digital literacy skills while the underlying principles are left uncovered. This situation has been recognised as a problem in many countries [17] and recently the introduction of computing in the curriculum in e.g. the

[1] The terminology varies between countries, for instance, in the USA "Computer Science" is a widely acknowledged term, while UK started to use "Computing" a few years ago.

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UK [4] and Estonia [16] has resulted in an increased debate throughout Europe. Another problematic issue concerns the view of computing as a male-dominated field, with girls losing interest in (or never even considering) computing as a career already at an early stage.

Bringing informatics to schools through curriculum changes in the form of a formal track is essential but this can also be supported in informal ways. Lately, we have witnessed an increased number of initiatives (e.g. code.org, Codeacademy, Hour of Code) aiming at making programming accessible to everyone. Similarly, the number of voluntary activities around informatics grows steadily through e.g. clubs such as CoderDojos, CodeClubs and MakerSpaces. Another similar activity is contests, for instance "Bebras", which is an international informatics contest providing motivating and game-like tasks in the format of multiple-choice questions and interactive problems to students in grades 2–12.

In this paper, we will focus on one specific age group (age 10–13) and analyse and compare the results of students in three countries: Finland, Sweden and Lithuania. Our goal is to bring light on the following questions:

- Are there notable differences in student performance among a) the three countries and b) boys and girls at this age?
- What cognitive skills are addressed in a set of Bebras tasks?

In the following we briefly discuss the status of informatics education in Finland, Sweden and Lithuania respectively. Next we describe the Bebras contest, after which we present the study setting and the results from analysing students' contest results. The paper ends with a discussion and some final words.

2 Informatics Education in Finland, Sweden and Lithuania

Students in all three countries commonly start school at the age of seven, when they enter comprehensive school. The structure and content of the education is based on national core curricula, which are renewed on a regular basis.

In **Finland**, informatics (including e.g. programming) was a compulsory subject at upper secondary level until 1994. Today informatics is not included as an independent subject in the current core curriculum for basic education (grades 1–9) [11], nor for upper secondary school level [10]. Instead IT is to be integrated in a given set of focus areas, which essentially means that students should learn to use technology in a responsible way and to use computers, software and networks for various purposes in different subjects. New core curricula will come into force in 2016 and are currently being drafted. A larger focus on both the use of informatics as well as e.g. programming, is to be expected.

In **Lithuania**, education is divided into three stages: primary (grades 1–4), lower secondary (grades 5–10) and upper secondary (grades 11–12). In 1986–2005 informatics was a mandatory subject at upper secondary level, with a strong focus on programming and algorithmic thinking (e.g. using Logo) [5]. In 2005 the subject was renamed to IT and the revisions resulted in less informatics topics being covered, focusing more on satisfying user needs and developing computer literacy. The curricula does, however, still include mandatory courses including e.g. programming. In grades 5–6 students should have approximately 15 lessons on Logo or Scratch. Similarly, in grades 9–10, there is a mandatory IT subject with several optional modules covering algorithms and programming. In grades 11–12, students can choose to learn several subjects at extended level, for instance programming modules preparing for studies at tertiary level. Students can also take an IT maturity exam, which mainly focuses on programming. New curricula are expected to be developed in 2016, and guidelines for introducing informatics and IT at all school levels are currently being drafted.

The current design of K-12 education in **Sweden** was established during the 1970s. Nine years of comprehensive school (primary and lower secondary education) is followed by three or four years of upper secondary school studies. ICT is commonly used as a tool at primary and secondary level for problem solving in other subjects and literacy. However, there is no such subject in school as computing or IT, as they are offered in Technology education in grades seven to nine. At upper secondary level, education is divided into different programs, e.g. focusing on natural sciences, technology, aesthetics or electronics. Programming courses are mainly offered at upper secondary school, in two separate courses, which are taken by students who attend one of the three programmes in technology, natural sciences or electronics. Hence, only a minority of students take programming courses.

3 Bebras – An International Informatics Contest

Different contests and olympiads [15,13] are arranged with the goal of introducing programming and other informatics domains to students. Contests make teaching of programming more attractive for students [18]. During contests students get to meet and compare their skills with peers from other schools, regions or countries [6,7].

The international Bebras [3] contest on informatics and computer fluency has been arranged since 2004 in a wide range of countries (29 countries took part in 2013). The contest was established and held for the first time in Lithuania in 2004, whereas Finland joined the network in 2010 and Sweden in turn in 2012. The main goals of the Bebras contest are to evoke interest in informatics among all students at an early stage, motivate them to learn and master technology as well as to develop their computational thinking skills [9].

The contest is organised in the second week of November in all participating countries. Contest arrangements vary slightly between countries, commonly the tasks are solved online under teacher supervision in a class room. The contest has five age groups: Little Beavers (grades 2–3 in Finland/Sweden and grades 3–4 in Lithuania), Benjamin (for grades 4–5), Cadet (grades 6–7), Junior (grades 8–9) and Senior for the oldest students. Depending on the country, the contest includes 15–21 tasks for each age group and students have 45–60 minutes time to finish the contest. Some countries use only four age groups, and there might be other small differences as well because participating countries have the freedom to adjust task sets based on their school system.

Bebras tasks are created and discussed in English during an international workshop, and each country then translates the tasks into the local language for use in the local contest.[2] Most of the problems are 4-choice questions related to information comprehension, algorithmic thinking, use of computer systems, combinatorics, discrete structures, puzzles or ICT and society [8]. In particular for the younger age groups, there are also motivating interactive tasks, where students answer by dragging and dropping objects, drawing lines, clicking on items, writing answers in text boxes, etc.

A contest with too many difficult tasks risks discouraging many of the participants, and vice versa, too many simple tasks will provide an incorrect view of informatics. Therefore tasks are categorised according to three difficulty levels - hard, medium and easy - with the intention to offer a balanced set of tasks within each age group. The scoring is in relation to these difficulty levels, as responses are mapped to 5, 4 or 3 points if correct, and -1,25, -1 and -0,75 points if incorrect. An unanswered question does not affect points at all. Initial points were given so that answering incorrectly to all questions gave 0 points. It should be noted that some countries use slightly different scoring systems.

4 Study Settings

4.1 Data Collection

This study is based on an analysis of the results from the Bebras contest held in November 2013 in Finland, Sweden and Lithuania. The total number of participants in the three countries respectively is given in Table 1, together with the corresponding distribution of boys and girls.

In order to answer our research questions (Section 1), we decided to focus our attention on one age group. We chose Benjamin (highlighted with grey in Table 1) for several reasons:

- The gender distribution is most equal for this group in all three countries (if not considering Minis).
- Students are still below the age where attitude changes towards computers and ICT commonly occur [14].
- Lithuanian students of this age should have at least 15 mandatory lessons on Scratch or Logo according to the IT curriculum.

Clearly, the number of Benjamins varied greatly between the three countries: Lithuania had over 7 000 participants, Finland roughly 850 and Sweden around

[2] In this process, it is naturally possible to arrive at somewhat different translations, which still mean the same, but that can be e.g. easier or more complicated to the students due to interpretations or misunderstandings in the translation phase. Finland and Sweden prepared tasks and translations together and consequently there should be only minimal differences between Finnish and Swedish task descriptions.

Table 1. Number of participants in Finland, Sweden and Lithuania in 2013

	Finland (X% boys, Y% girls)	Sweden (X% boys, Y% girls)	Lithuania (X% boys, Y% girls)
Mini	826 (52%, 48%)	262 (49%, 51%)	2 176 (55%, 45%)
Benjamin	852 (50%, 50%)	201 (56%, 44%)	7 022 (54%, 46%)
Cadet	1 294 (55%, 45%)	451 (55%, 45%)	6 550 (57%, 43%)
Junior	1 281 (69%, 31%)	413 (54%, 46%)	6 490 (60%, 40%)
Senior	170 (78%, 22%)	471 (91%, 9%)	3 671 (68%, 32%)
Total	4 423 (58%, 42%)	1 798 (63%, 37%)	25 909 (58%, 42%)

200. Nevertheless, when implementing the same tasks in the countries, we believe the differences in both language and school system contribute to a research setting where specific concepts can be studied.

In Finland and Sweden, Benjamins are aged 10–11 (grades 4–5), whereas Lithuanian Benjamins are a bit older (aged 11–13, grades 5–6). Students in this age group need to solve 21 tasks during 45 minutes in Lithuania and 15 tasks during the same time in Finland and Sweden. This is important to keep in mind when analyzing the data, but on the other hand Lithuanian students were somewhat older and might also have some experience with informatics concepts from their education, which could even out the situation.

4.2 Methodology

Our analysis is divided into two parts: first, we give an overview of the Benjamin results separately for each country as well as compared to each other. Second, we select 12 tasks common to all three countries for closer examination.

As mentioned in Section 3, all Bebras tasks are categorized based on the problem type (algorithm, computer use, puzzle, etc.) and difficulty level during the international workshop. In this study we also wanted to make a first attempt at introducing a common framework for categorizing tasks based on cognitive skill level. We chose Bloom's taxonomy [1], which is widely used for classifying educational objectives, and used content analysis of task descriptions for conducting the categorization. The cognitive domain in Bloom's taxonomy contains six hierarchical levels starting from simply remembering going to more complex cognitive skills:

1. **Remembering:** Recalling previously learnt information.
2. **Understanding:** Comprehending the meaning, translation, interpolation, and interpretation of instructions and problems.
3. **Applying:** Using a concept in a new situation or unprompted use of an abstraction.
4. **Analyzing:** Separating material or concepts into component parts so that its organisational structure may be understood. Distinguishing between facts and inferences.
5. **Evaluating:** Making judgments about the value of ideas or materials.

6. **Creating:** Building a structure or pattern from diverse elements. Putting parts together to form a whole, with emphasis on creating a new meaning or structure.

5 Results

5.1 Overall Performance in the Benjamin Age Group

The distribution of the total scores of Benjamins in the three countries are given in Fig. 1, Fig. 2 and Fig. 3 respectively.

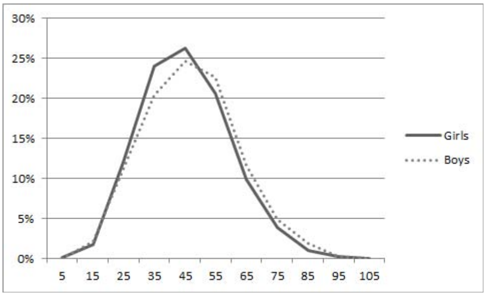

Fig. 1. Proportion of Lithuanian Benjamins achieving a given number of scores (7 022 participants, 21 tasks, maximum score 105)

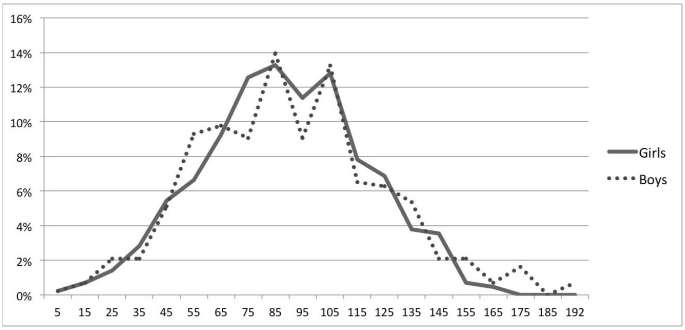

Fig. 2. Proportion of Finnish Benjamins achieving a given number of scores (852 participants, 15 tasks, maximum score 192)

As we can see from the Lithuanian and Finnish diagrams (Fig. 1 and Fig. 2), the results in these countries nearly follow the normal distribution. In Lithuania, the overall difficulty level of the tasks may have been somewhat too high for this age group as the bell curve is shifted slightly to the left. The curve does, however, show that the task set was in good balance: few students received scores around zero and few students reached the highest score. The Finnish curve is more centred around the mid score, but shows some interesting drops in the graph depicting boys' results at this point.

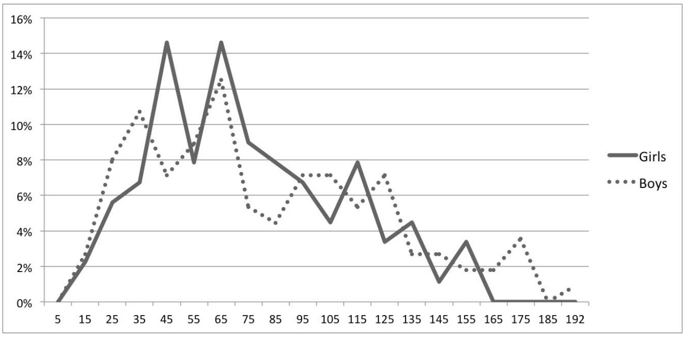

Fig. 3. Proportion of Swedish Benjamins achieving a given number of scores (201 participants, 15 tasks, maximum score 192)

As stated above, there was a large difference in the number of participants in the three countries: Lithuania's diagram is based on contest data gathered from over 7 000 participants and Finland's illustrates the results of over 850 students. In Sweden, however, the number of Benjamins was lower (201). This is quite natural, given that this was only the second time that the contest was held. Despite the low number of participants, the diagram still resembles a normally distributed curve, with some spikes and shifted to the left. In the future, when the contest will attract more participants, the results and the curve can be expected to be smoother.

5.2 Analysis of Selected Tasks Based on Cognitive Domains

Traditionally Bloom's taxonomy has been used to connect a particular teaching or training element with a certain cognitive domain level. For instance, a multiple-choice test is commonly regarded as an example of the first level - remembering or recalling information. When creating multiple-choice questions for Bebras, each task should target a given cognitive skill, focusing on student learning and understanding, not merely on recalling already known facts.

The task sets for Benjamins in Finland, Sweden and Lithuania had 12 tasks in common: 10 multiple-choice and 2 interactive ones. We analysed the descriptions for these tasks using content analysis according to their complexity from three viewpoints: a) what types of informatics concepts are hidden in the task b) how complex is the task in order of understanding, and c) do students need to follow only the given instructions or should they also apply new knowledge obtained from the task description? The results of the analysis are presented in Table 2.

5.3 Closer Analysis of 12 Tasks in Common

The proportion of correct answers for the 12 tasks in common are given in Fig. 4 and Fig. 5. The tasks are listed in order of difficulty level (assigned by the contest organisers) from easy to hard.

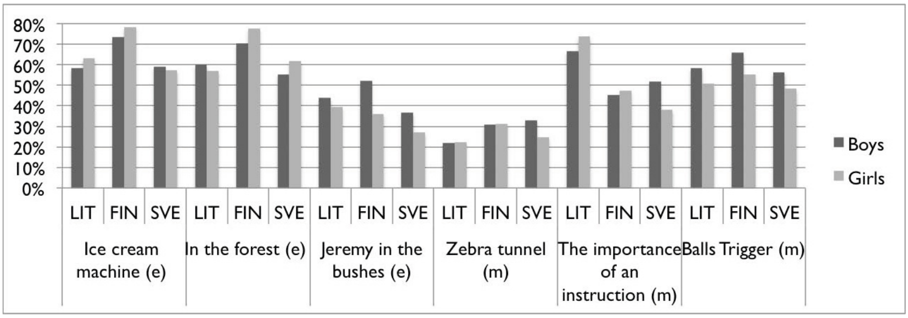

Fig. 4. The difference in relation to gender and country for six of the tasks in common. The difficulties are abbreviated as e = easy, m = medium and h = hard.

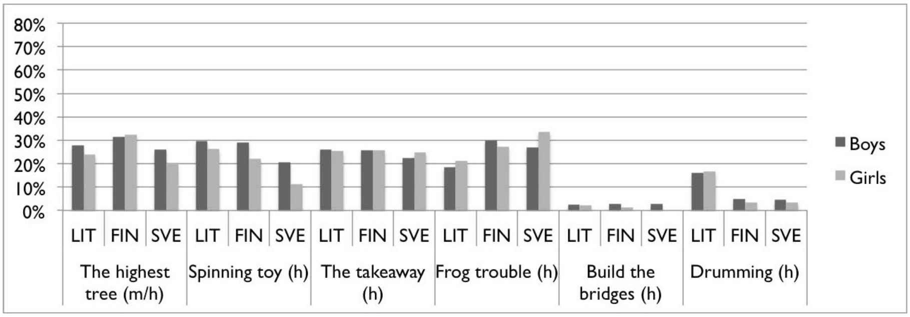

Fig. 5. The difference in relation to gender and country for the remaining six tasks. The difficulties are abbreviated as e = easy, m = medium and h = hard.

As the diagrams illustrate, the assigned difficulty level matches the actual difficulty level for many tasks (e.g. the first two easy ones and all the difficult ones), whereas some tasks seem to have been either easier (e.g. "Balls Trigger") or more difficult (e.g. "Zebra Tunnel") in practice.

The task description for "Zebra Tunnel" was slightly different in Finland and Sweden compared to in Lithuania. In Finland and Sweden the task required students to choose the correct answer from four alternatives (multiple-choice), whereas Lithuanian students were to calculate the answer and submit it in a text box (short answer). Consequently, one can assume that this particular task was more difficult for Lithuanian students as they needed to solve the task precisely without getting any help from alternative answers provided in the task.

Table 2. The 12 Bebras tasks in common, described in terms of cognitive domains (revised Blooms taxonomy)

Task name	Difficulty level	What concepts are involved in the task	Cognitive domain
Ice cream machine	Easy	detecting an algorithm; machine work; sequencing; loop	**understanding** description of non-trivial process; detection the operation of an algorithm; steps of algorithm instruction
In the forest	Easy	graph; tracing; route planning; backward strategy	**understanding** situation and planning a route from the end; separating and organising objects under given rules; distinguishing between input and result
Jeremy in the bushes	Easy	algorithm; robot navigation; tracing	**understanding** given generative rules to an input and situation; following simple; 3–5 steps algorithm instruction
Zebra tunnel	Medium	to follow instructions; algorithm analysis; data structures: FIFO (queue) and LIFO (stack)	**applying** non-trivial rules of behaviour of animals; there are representation of two ways to put data in a structure and retrieve it later; steps of algorithm instruction
The importance of an instruction	Medium	instruction; human machine instruction; unambiquous instruction	**understanding** description of processes and rules of behaviour of your partner; imagine the steps of an algorithms; interpretation of instructions
Balls trigger	Medium	instructions; logics; trigger; logical gate	**understanding** given generative rules and instructions to an initial state; following logical derivation
The highest tree	Medium (Fin/Swe), hard (Lit)	following instruction; repetition; searching algorithm; local optimisation; global optimum	**applying** given few steps non-trivial instructions with repetition; strictly following a list of prescribed instructions
Spinning toy	Hard	binary tree representation; tree traversal; operations abstraction	**applying** - identifying constituent parts and functions of an object; de-construct a process, final state or final product; applying high level abstraction
The takeaway	Hard	memory; management of data structure; stack	**applying** a given complex rule to the process; processing objects as data combinations (data structures)
Frog trouble	Hard	shortest path; breadth-first search algorithm	**applying** given instructions in the process; going from one state to another state; invention of efficient algorithm
Build the bridges (interactive task)	Hard	graph; tree; minimum spanning tree; Kruskal's algorithm; Prim's algorithm	**creating** - reviewing strategic plan in terms of efficacy; building a structure (bridges connecting islands) from diverse elements under rules; putting parts together to form a whole and to count values
Drumming (interactive task)	Hard (Fin/Swe), easy (Lit)	iteration; repetition; loops; following instructions	**analyzing** sequences (rhythms) and understanding repetition; using patterns (component parts) to organise required structure

This difference might explain the sudden drop in performance for Lithuanian students for this task (almost 10% difference in scores between Lithuanian students and Finnish/Swedish students).

The two tasks having the highest proportion of correct answers (70% or more of both boys and girls answering correctly) are "Ice cream machine" and "In the forest", in which Finnish students managed very well. The former of these tasks addresses skills from the understanding domain, whereas the latter one maps onto a higher level domain (analyzing). Interestingly, Lithuanian and Swedish students have done almost equally well on both of these tasks.

The two tasks at the end of the diagram in Fig. 5, "Build the Bridges" and "Drumming", appear to hold some difficulties. These are interactive in all three countries. "Build the bridges" expects students to create, e.g. use a cognitive skill at the highest level. The task involves building a structure (bridges connecting islands) from diverse elements under given constraints and rules, putting parts together to form a whole and to count values.

Similarly, "Drumming" addresses both creation and analysis skills as students are required to build a sequence (rhythm) based on a set of given patterns (components or parts). This task hence also assumes some understanding for concepts such as repetition (iteration) and symbolic language, which can explain the somewhat better results in Lithuania where students are expected to have some background in programming. Another task associated with algorithms and programming is "The importance of an instruction" (Fig. 4), in which students need to interpret and understand how to combine precise instructions. This task was also solved with better results by Lithuanian students.

The results show that there is no notable difference in the performance of boys and girls. Girls performed better than boys on several tasks, for example "Ice cream machine" (Lithuania and Finland), "In the forest" (Finland and Sweden) and "The importance of an instruction" (Lithuania and Finland). Boys, on the other hand, did better on for instance "Jeremy in the Bushes", "Balls Trigger" and "Spinning Toy" in all three countries.

Finally, the diagrams indicate that there is close to no spread between the countries for two tasks: "The takeaway" and "Build the bridges". These two tasks are interesting as the variables under investigation (gender, country and task) seem to have minimal influence on the contest outcome. These tasks could therefore be expected to hold non-biased qualities, in relation to the variables.

6 Discussion and Future Work

The distribution of scores from the three countries resemble the normal distribution to different extents. If the results from all three countries had been merged, we would have ended up with something very close to an exemplary bell curve. In this paper we, however, wanted to keep the student groups separate in order to make it possible to reveal any issues between countries and gender.

As stated in the introduction, informatics is still a male-dominated discipline, but our results suggest that girls aged 10–13 manage equally well (or even better) than boys in this contest. Overall, the results in relation to gender are quite balanced (see Fig. 4 and Fig. 5). Since self-confidence and perceived self-efficacy seem to play a big role for students' choice of further studies [2], the Bebras contest appears to be one way of increasing girls' belief in their own skills and knowledge in informatics. A more detailed analysis of the tasks (type, area, content) solved better by boys and girls respectively would be very interesting, as this could reveal some useful information on e.g. the characteristics of gender-neutral tasks, i.e. tasks appealing to both boys and girls.

When comparing the results from the three countries, we can see a difference in particular for tasks related to programming and algorithms (e.g. "The importance of and instruction" and "Drumming"). Lithuanian students managed notably better on these tasks, which can be explained at least partially by these students having experience in Logo and/or Scratch. Hence, these students can be expected to be familiar with instructions in the form of commands and procedures, whereas Finnish and Swedish Benjamins are most likely not exposed to programming at school.

The tasks included in the 2013 contest seem to have been somewhat too difficult for the Benjamin age group, as the bell curves are slightly shifted to the left for all three countries. The diagrams in Fig. 4 and Fig. 5 give good indications on how well the difficulty level assigned to a given task by the contest organisers corresponds with the actual difficulty level. For instance, "Zebra Tunnel" (Fig. 4) was originally labelled as a medium task, but having seen the results, we can conclude that it seems to have been more difficult than expected. Deciding on a suitable difficulty level for a given task upfront is quite difficult. Hence, coming up with an efficient and valid way of creating good tasks and evaluating them is a main priority both for us as researchers and for the Bebras community as a whole. To some extent the actual difficulty level seems to correlate with the classification in Bloom's taxonomy. It might hence be worthwhile to classify each task picked for a given age group before assigning the difficulty level.

The data presented in this paper do not provide any insight into the number of "guesses", that is, students merely choosing an answer at random instead of leaving it blank. An initial review of the detailed response data from the contests suggests that guessing is something worth further investigations, and we will study this in an upcoming paper. As a selection process is omnipresent in the school system, we will also continue our analysis by looking into the results of other age groups in order to investigate e.g. if, and in that case when, a difference in participation rates and results between boys and girls become notable.

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