Eight-Year-Olds' Conceptions of Computer Viruses

A Quantitative Study

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ABSTRACT

Many eight-year-olds use mobile devices. These devices can be attacked by computer viruses, with possible, serious consequences for device owners. Eight-year-olds do not always learn in schools about the concepts of computer viruses and protection against them, but they may still have everyday conceptions about these concepts: acquired outside schools. However, little is known about whether or not children have these everyday conceptions, and if so, how elaborate they are. This study explores these conceptions among 58 second graders from the Czech Republic, who were not taught about computer viruses in school. The children were interviewed, their correct conceptions were quantitatively scored, and their incorrect notions were noted. The results showed that children had few incorrect notions; however, their understanding was generally low and patchy. Approx. 1/3 of the children knew about the existence of software updates, but – and this is especially worrying – almost none of them knew about antiviruses. On a practical level, the results support the idea that the topic of computer viruses should be taught early at the primary education level. On a theoretical level, within cognitive constructivism frameworks, the results indicate that children's understanding has to be developed from scratch rather than by means of reconstructing and/or elaborating already held conceptions (because children appear to bring few prior conceptions to school, neither correct nor incorrect ones).

CCS CONCEPTS

• Social and professional topics → Computing literacy; K-12 education; Student assessment

KEYWORDS

Primary computing education, primary school children, computer viruses, antiviruses, software updates, conceptions

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1 INTRODUCTION

What conceptions about computer viruses and protection against them do eight-year-olds have? This is an important issue, because available (albeit limited) evidence indicates that primary school children are frequent users of smartphones and certain internet services [13] (we use the term 'primary' to refer to Grades 1-5). There are many safety issues stemming from use of internet-connected devices: computer virus attacks are among them. Children can be vulnerable to such attacks, especially if they lack relevant knowledge.

Despite a recent renaissance in primary computing education and research (e.g. [21, 28]), little is known about what primary school children know about *any* computer-related aspect (including computer viruses). First, examination of general computing knowledge and skills among primary school children has so far remained outside the scope of large, international, comparative studies. For instance, the pioneering ICILS study [14] focused on 8th graders. Second, a handful of small-scale studies have so far mapped how pre-tertiary learners understand various facets of how computers and computer networks function (e.g. [7, 8, 18, 24, 25]). However, most of these studies focused on pre-adolescents and adolescents (e.g. [3, 4, 15]), some are relatively extant (see [26] for a review) and as far as we know, only two of them focused partly on the notion of computer viruses [6, 18]. Third, information in academic literature about what is taught about computer viruses in primary schools appears to be limited (e.g., cf. [2, 16, 21, 28]).

It is quite possible that younger primary school children, at about the age when they start to use smartphones, have only patchy understanding of computer viruses: from non-school contexts rather than from schools as such. Therefore, in the case of these children, there may be a high risk of computer virus attacks (and this attack can have serious consequences for them).

What *prior conceptions* about viruses, such as spyware or ransomware, and protection against them do children bring to schools? Is there a large degree of heterogeneity in levels of scientifically normative knowledge about viruses among children? Do children have incorrect conceptions that could have a harmful impact on their usage of computing devices? (For instance, in *Ralph Breaks the Internet*[1], a computer virus is depicted as a smart technology able to detect bugs and errors in programs and replicate or inject the found error into other programs or web pages. This may give an incorrect impression that one has to fight smartness of computer viruses, rather than understand consequences of inappropriate user actions and the necessity to update buggy programs.)

The goal of the present study is to explore elementary understanding of the concept of computer viruses and protection against them among children in the second half of 2nd grade in the Czech Republic, where computer science is not obligatory at the primary education level. This understanding includes the following concepts:

- the very notion of a computer virus,
- how computing devices can (and cannot) be infected,
- what harm can viruses do, and
- what antivirus and software updates are.

By accomplishing this goal, this study contributes on both practical and methodological levels. On the practical level, knowing what prior conceptions children have about viruses is important for considering when and how to integrate this topic into curricula and how to "reconstruct" children's misconceptions if needed (cf. [6, 12]). On the methodological level, knowledge of how to measure levels of understanding of viruses in a quantitative way (gained in this study) can help in designing future, large-scale intervention studies and/or cross-cultural comparison studies (which typically need quantitative measures of target knowledge).

In particular, this study examines the following questions:

1. What is the level of children's understanding of the topics listed above? We hypothesize that this level is generally low **(H1)**, because these children have not been exposed to these topics in schools.
2. What is the variability in children's understanding of these topics? We hypothesize that this variability is relatively large **(H2)** owing to the lack of central exposure to the topics, but possibly varying exposure outside schools. Specifically, we hypothesize that many children will have no understanding at all, but that we will find a few "experts" (i.e., experts with respect to what can be reasonably expected from second graders).
3. To what extent is knowledge about these topics fragmented? We hypothesize that it is fragmented even among children with above-average understanding of the topics **(H3)**, because even these children have been unlikely exposed to these topics systematically.
4. How many incorrect conceptions about these topics do children have? We hypothesize that incorrect conceptions are relatively common **(H4)**, because they are not likely to have been "corrected" in schools.

Section 2 describes the theoretical background and what is known about children's conceptions about computing systems. Section 3 describes our research methods. Section 4 introduces results, and Section 5 discusses them and offers conclusions.

2 RESEARCH BACKGROUND

2.1 Cognitive Constructivism

Nowadays, cognitive constructivism frameworks are widely used in science education (e.g. [9, 11, 20, 23]), including computing education (e.g. [6, 12]), as models of knowledge acquisition (see e.g. [19], and Part II of [27], for a discussion of other models). Within these frameworks, knowledge is constructed by learners in their minds: not only based on exposition to instruction, but also based on learners' prior conceptions (often acquired in informal contexts) and depending on learner's cognitive effort. Some of the prior conceptions may be incorrect, partly correct or incomplete. Some of them may be resistant to change and may need to be reconstructed in elaborate ways within newly built knowledge structures (e.g. [10, 11]). Cognitive constructivism frameworks not always agree on how this reconstruction happens (or should happen in school) (e.g. [9, 23]). Still, the common message is that it is useful to map learners' conceptions acquired from informal contexts before one starts to design educational intervention. Our study presents this step.

2.2 Children's Computing Conceptions

Children's, pre-adolescents' and adolescents' conceptions about specific computing concepts are predominantly outside the focus of international studies comparing computing knowledge,

[1] https://www.imdb.com/title/tt5848272/ (Accessed 16-06-2019)

computing skills or cyberspace-related behavior: such as ICILS [14], PISA [22] or EU Kids Online [13]. However, they have been examined in several small-scale "mapping" studies. These concepts include, for instance, databases [5], internet [7, 8, 24], social networks [4], smartphones [3] or computers in general and/or their functioning [15, 25] (see also [26] for review of older studies) (the literature on understanding programming concepts and misconceptions, e.g., [27, 29], is outside the present scope). All in all, these studies tentatively indicate that pre-tertiary students' understanding of computing concepts is incomplete and fragmented, with possibly large variance in understanding. This may be explained by the fact that many countries still are not likely to have integrated, or have only partially integrated, these topics into pre-tertiary curricula, cf. [1, 16]. In many instances, schools may not be the primary source of students' knowledge about computing concepts. Consequently, some students may know little because of their lack of exposure. Others may know a lot thanks to their interest in the topic and/or out-of-school influences. However, the research base for what pre-tertiary students know about computing topics (and how these topics are taught in different countries) is itself patchy.

As far as we know, only a few recent studies have examined the computing conceptions of children up to around Grade 5 [8, 18, 25] (also, the review [26] includes several such studies published up until 2008). Of these studies, only one extant study conducted in 2005 [18] examined conceptions of computer viruses. The authors posed two open-ended questions (on what a computer virus is and how to protect a computer against getting it) to three age groups (6-11, 12-14 and 15-18 year olds) of participants of a virtual learning environment. The study did not quantify individual participants' levels of knowledge, but in general, the authors were able to conclude that "large majority of online users have little understanding of a computer virus" (p. 528). For example, less than 10% of any age group understood computer viruses in computational terms (e.g., it is a computer program). However, more than 50% of any age group knew that protective actions against viruses can be taken (e.g., antiviruses, firewalls etc.). The participant distribution within age groups is unclear, so it cannot be determined whether the youngest group consisted of, say, more fifth graders compared to first graders.

Conceptions of viruses were also examined in one interview study with a heterogeneous German sample [6] conducted in 2012. The sample included mainly higher education learners and 10% of "school students" (without specifying the participants' ages). The study also did not quantify individual participants' levels of knowledge about viruses, but based on the frequency of responses in the interviews, the authors concluded that there was "strong awareness of the risks, but a weak understanding of the working principles of viruses" (p. 171) among the interviewees. This paints a picture of incomplete knowledge even among (predominantly) higher education learners.

Because the two studies above were carried out more than 7 years ago, some caution is needed in interpreting their findings: the situation could have changed. Altogether, it is safe to conclude that almost nothing is known about students' conceptions about computer viruses: especially, at the primary school level. This study aims to take steps to fill this gap.

3 METHOD

3.1 Design

This research was conducted as part of a larger, 90-minute-long, classroom intervention study (irrelevant for present purposes) that concerned a computer literacy-related topic. That study included 14 different classes in seven different, conveniently selected, public schools (see Sec. 3.2 for how these schools were selected). At the beginning of every experimental session, we conducted (directly in classrooms) short, semi-structured interviews that we recorded on voice recording devices. Interviews with select participants were analyzed for the purpose of the present study.

3.2 Participants

For this study, we included a random selection of two boys and two girls from every class (N = 58; 29 girls and 29 boys, 7-8 years old, 2nd grade). All interviews were organized between March and May 2019; i.e., in the second half of the 2nd grade.

The schools were from the capital of the Czech Republic and suburban areas. All schools were regular public schools (86% of primary schools in the Czech Republic are public schools). The sample of schools was not representative; rather, we included schools within a reachable distance and whose boards were willing to participate in the research. Nevertheless, the schools and their classes (and thus the participants) can be viewed as a sample from a mainstream school audience in the capital and its suburbs.

None of the children selected has learned the respective topics at school.

We were not able to collect data on participants' use of mobile phones. However, it was apparent in the classrooms that >50% of children had their own smartphones. A few also mentioned (in the debriefings after the entire study) that their devices had probably been infected by computer viruses in the past (the children described the symptoms; they were rarely sure that the problem had been caused by a computer virus attack).

3.3 Interview Structure

Because we wanted to measure children's knowledge in a quantitative way, we used a method frequently employed in the field of multimedia learning to assess conceptual understanding (see, e.g., [20]). This method is based on posing open-ended questions on key concepts and scoring answers by looking for mentions of key "idea units", i.e., units of understanding the concept in question. In multimedia learning, these questions are typically given to adolescent or adult participants in written form. We have adapted this method for interviews with primary school children in laboratory environments [17].

Based on our research question, we started by defining (a priori) three basic concepts in order to evaluate children's knowledge. These concepts included the following: *computer* *virus, antivirus* and *software update*. Next, we specified (based on a pre-study and our expert knowledge) the following questions that we used to guide the interview:

1. *What is a computer virus?*
2. *Could you explain how a virus gets into a computer?*
3. *What harm do you think computer viruses do?*
4. *What is an antivirus?*
5. *Do you know what software updates are?*
6. *Do you know why we need them?*

3.4 Procedure

Each participant was interviewed individually by a trained research assistant. Interviews typically lasted 1-3 minutes (this was because children generally knew little, as detailed in Sec. 4). The research assistant posed each question to stimulate the participant to verbalize freely his/her understanding. If the child gave any answer at all to the question, he/she was further encouraged 'to go on' after he/she stopped talking (at most twice for each question). If the child could not provide any answer, he/she was assured that this was not a problem, as they probably had not learnt about the given concept at school yet. The assistant could slightly adapt the wording of questions (but not the meaning) based on circumstances (especially when a child knew nothing or when his/her answer related to a not-yet-posed question; e.g., when the child did not answer Q1, Q2 could be modified as follows: *By chance, could you explain how…*). In the cases of Q1, an additional cueing question was used if the child had given any sort of answer: *Would you know in what type of computing devices we can find computer viruses?*

The interviews were organized during mornings from Tuesday to Thursday (i.e., the whole experimental session was part of a school day). Only children having parental consent were included. The research was approved by the ethical committee of the Institute of Psychology of the Academy of Sciences of the Czech Republic.

3.5 Coding

Interviews were transcribed and evaluated by means of a coding rubric, which included, for each question, a number of key idea units that a child could mention. For each correct idea unit, the child received 1 point (in specific cases, 0.5 or 0.25 points could be given for incomplete or partially correct idea units). The total test score was computed by tallying points given for each question.

The rubric was created by us in advance based on a) expert answers and b) the answers of children from a pre-study. For example, the coding rubric for 'Q1 – *What is a computer virus?*' included a) a program; b) something that does harm; c) something that can attack a computer/tablet/smartphone (the child had to mention at least two devices; in the case he/she mentioned only one device, he/she was given 0.5 point). Exact wording was not required (e.g., the child could say 'mobile phone' instead of 'smart phone'). The child was given points even if he/she mentioned the correct answer for a specific question as part of the answer on a different question. Answers to Q5 and Q6 were analyzed together, because it was difficult to separate children's answers to Q5 from those to Q6 (e.g., children sometimes defined software updates as part of the answer to Q5 in terms of 'why it is needed', which is Q6).

For example, a child would be given 1.5 points for the following answer on Q1: "Virus is… mmm… in computers … it harms them." (the child was given 0.5 point for 'computers' and 1 point for 'harms'). At most, 28 points could be given for the whole test (see Table 1 for possible ranges for each question). However, the following example illustrates what we would consider a "child expert" answer: "Virus… it harms computers or mobile phones. You have to pay attention to what you download, because you can download a virus. For example, the virus can spy on you, it can send out your data. An antivirus can protect your phone against viruses, but it cannot undo the harm caused by the virus. Software updates make your computer and your antivirus better." This answer would be awarded 10 points.

Answers from 10 children were analyzed by two coders until a consensus, as concerns the interpretation of children's answers, was reached. Answers from the remaining children were analyzed by a single coder.

Aside from quantitatively evaluating the answers, we wrote down metaphors through which children expressed their understanding and incorrect notions (i.e., in order to address Hypothesis 4).

4 RESULTS

4.1 Hypothesis 1: Level of Understanding

Table 1 shows a breakdown of children based on the number of points they obtained for each question. Children's knowledge about computer viruses was generally very low. Nineteen (~33%) children knew nothing about this topic. Only 25 (~43%) were awarded at least one point (i.e., ~3.6% of total possible score). Therefore, **Hypothesis 1 is supported**.

4.2 Hypothesis 2: Between-child Variability

Only four children received more than 4.2 (15%) points (see Figure 1 for overall test score distribution). Therefore, there is only limited variability between children in their understanding of computer viruses (i.e., all the children knew little or nothing about the topic).

Despite the fact that the best-performing children (say, the Top 10) can hardly be viewed as "child experts", it is worth examining how their answers differ from the answers of the other children. Children from the former group typically expressed themselves better as concerns Q1 (*What is a computer virus?*) compared to the remaining children and they had at least one idea related to Q2 (*Could you explain how a virus gets into a computer?*) or Q3 (*What harm do you think computer viruses do?*).

All in all, there is only **partial support for Hypothesis 2**, as even the best performing children can hardly be viewed as "child experts".

Table 1. Breakdown of children based on the number of points they obtained for each question.

Questions	Average points per child	Average points per child (in percent)[a]	Numbers of children who obtained the following points for each question				
			0.00	0.25 – 0.75	1.00 – 1.50	1.75 – 2.25	2.50 – 3.00
1. What is a computer virus? *(range 0-3)*	0.69	22.84%	34	3	10	5	6
2. Could you explain how a virus gets into a computer? *(range 0-7)*	0.13	1.85%	50	2	6	0	0
3. What harm do you think computer viruses do? *(range 0-10)*	0.20	1.98%	45	9	2	1	1
4. What is an antivirus? *(range 0-2)*	0.06	3.02%	55	1	1	1	–
5. & 6. Do you know what software updates are? Do you know why we need them? *(range 0-6)*	0.21	3.52%	34	22	2	0	0
Total: all questions *(range 0–28)*	**1.29**	**4.59%**					

[a]Average number of points given for the question divided by the maximum number of points that could be given for this question.

4.3 Hypothesis 3: Knowledge Fragmentation

Considering our five questions, the children best answered the first one (i.e., *What is a computer virus?*). The average success rate in Q1 was ~23%. At the same time, ~53% of all the points awarded to the children in the test was given for answers to Q1. On the contrary, the term antivirus was almost unknown to the children (Q4) – see Table 1. Children demonstrated a variable level of awareness of the existence of software updates (Q5+6) – ~1/3 was awarded at least 0.5 point (e.g., for mentioning that updates are something that is downloaded or that updates make games better/newer).

The remaining questions (Q2, Q3) concerning the mechanisms behind computer viruses were difficult for the children: they generally did not know the answers. Thirty-eight children (~66%) were awarded 0 points for both of these questions. All the remaining children, except for the best performing one, received 0 points for one of these two questions and 0.5 – 2.5 points for the second question.

Only the best-performing child, who was awarded 6 points in total, was awarded some points for every question. This child's answers were as follows:

Q1. "It something that… when it gets inside a computer, it causes the electronic device to act up or have problems." *(0.5 for 'computer'; 1 for 'to act up or have problems'; additional 0.5 for 'tablet or mobile' from Q3)*;

Q2. "Through different apps… a person can send it to you." *(0.5 for 'through different apps'; 1 for 'a person can send it to you')*;

Q3. "It can delete or replace a game in a tablet or mobile." *(1 for 'delete'; 0.5 for 'replace')*;

Q4. "It's a program that destroys viruses… once you install it." *(1 for 'a program that destroys viruses')*;

Q5+6. "When something is downloaded." *(0.5 for 'downloaded')*.

All in all, we see that the children knew the concepts separately (if at all). They rarely linked different concepts together. We conclude that **Hypothesis 3 has been supported**.

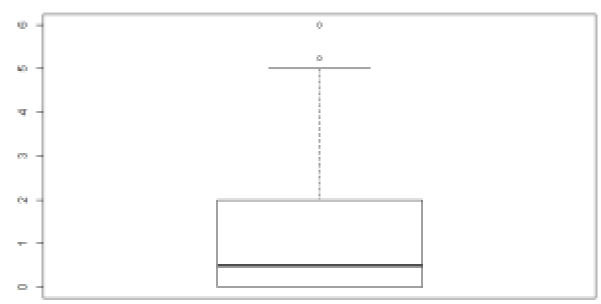

Figure 1: Box plot for Test score variable. The vertical size of the box denotes the interquartile range. Whiskers represent 1.5 × interquartile range. The possible test score range is 0 – 28.

4.4 Hypothesis 4: Incorrect conceptions

Children had almost no incorrect conceptions, and they rarely used metaphors to express themselves. We found only two cases. The first one was the idea that a virus and an antivirus program are like a disease and a medicine (*n* =4). In this study, participants received 0 points for these answers (because participants anthropomorphize a virus and an antivirus program in these answers). However, given the age of our participants, it is difficult to view this idea as a completely incorrect notion. Within cognitive constructivism frameworks, it is rather an idea, based on which one can build a more elaborate understanding in school lessons. The second one was a truly incorrect conception: that a virus can enter a computer through its fan ($n = 1$).

All in all, **Hypothesis 4 has not been supported**. Children's incorrect conceptions about computer viruses and antiviruses appeared to be rare.

5 DISCUSSION AND CONCLUSION

This study expands our understanding of what primary school learners know about computing topics (cf. [8, 18, 25]; see also [26]). Specifically, we asked what second graders knew about the notion of computer viruses, how the viruses can enter a computer, what harm they can do, what an antivirus program is and what a software update is, and why it is needed. The answer is that our participants knew very little and the knowledge of the few who did know a bit appeared to be fragmented. There were no clear "child experts" among our participants. Finally, children rarely had incorrect conceptions.

Prior to our interviews, our participants were not exposed to the topics of a computer virus, an antivirus program, and software updates in school. Therefore, our findings indicate that they were not able to acquire the respective knowledge in informal contexts: from parents, friends and media. The fact that they did not have incorrect conceptions due to entertainment media exposure is a positive sign. Otherwise, this study's outcomes are alarming. Especially worrisome is the finding that almost no one knew about antivirus programs. We literally saw many of our participants using smartphones, and some made it clear in the debriefing after the entire experimental session that their phones had most likely been attacked by computer viruses. Apparently, parents of these children were unable to keep their children's devices (and thus the children) safe. How should these children protect their devices or ask someone for help when they do not know what an antivirus program is?

This study's clear practical implication is that children have to be exposed to the topic of computer viruses and protection against them early in primary schools. It cannot be argued that they are too young, because they already use devices that can be attacked by computer viruses. Nor can it be argued that they will acquire understanding outside schools, e.g., from parents: this study made it clear that the vast majority of them will not. Designing a model school lesson for teaching these topics is our next step. The results suggest that children have almost no incorrect conceptions. Therefore, from the perspective of cognitive constructivism frameworks, their understanding has to be built (i.e., in the lessons) from scratch (~33% of our sample achieved 0 points) or based on very limited, fragmented, but more or less correct knowledge of the target concepts (rather than based on elaborate, but normatively incorrect, prior conceptions).

On the empirical level, it is worth pondering on why our participants knew little about antiviruses, unlike participants of the study by Kafai [18]. One possibility is that the previous study might include an older sample: It reported on the subsample 6-11 years of age, but without providing details on age distribution. These participants were recruited through an online learning platform, so the age distribution could have been skewed toward upper half of the interval. Another possibility is that that study was conducted in 2005 when the key technology of question was PC. It is possible that knowledge about protection of general computers was more widespread compared to knowledge about how to protect a smart phone, which is arguably the primary computing device of present-day primary school children.

On the methodological level, the positive message is that we were able to measure children's knowledge quantitatively directly in noisy school environments (we used this assessment method previously only in a research lab). Still, it is a challenge for future research to scale up this approach, because the participants were interviewed individually. This is not practical, for instance, for whole-class assessment.

This study is not without its limitations at the scientific level. First, our sample can be viewed, to some extent, as representative with regards to mainstream school audiences in the capital and suburbs of the Czech Republic. This is actually an improvement with respect to the majority of previous small-scale studies mapping students' conceptions about computing topics (e.g., [3, 4, 25]). Nevertheless, it remains a question whether or not the present findings will generalize to the rest of the country or to different countries. For example, it is possible that in other countries parents will educate their children about computer viruses when they give them their first mobile phone (which does not seem to be the case in 2019 in the Czech Republic). Second, our results cannot be generalized to situations in which children were exposed to the respective topics in formal education systems. It is an important, yet so far scientifically unaddressed, question as to how much eight-year-olds can actually learn about these topics. We plan to examine this question in our subsequent study. Third, we did not have robust data on the use of mobile phones. It would be useful if correlation between the use of mobile devices and knowledge about protection against computer viruses were examined in the future.

Overall, this study contributes to the literature examining learners' knowledge about computing topics. It can be viewed as one of the steps toward a much needed international, comparative study assessing learners' computing knowledge on a large scale. At the same time, this study made the case that teaching about computer viruses and protection against them should be included early at primary level.

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REFERENCES

[1] Balanskat, A. and Engelhardt, K. 2014. *Computing our future: Computer programming and coding-Priorities, school curricula and initiatives across Europe.* European Schoolnet.

[2] Barendsen, E., Mannila, L., Demo, B., Grgurina, N., Izu, C., Mirolo, C., Sentance, S., Settle, A. and Stupurienė, G. 2015. Concepts in K-9 computer science education. In *Proceedings of the 2015 ITiCSE on working group reports*. ACM, 85-116.

[3] Brinda, T. and Braun, F. 2017. Which Computing-Related Conceptions Do Learners Have About the Design and Operation of Smartphones?: Results of an Interview Study. In *Proceedings of the 12th Workshop on Primary and Secondary Computing Education*. ACM, 73-81.

[4] Brinda, T., Kramer, M. and Beeck, Y. 2018. Middle School Learners' Conceptions of Social Networks: Results of an Interview Study. In *18th Koli Calling International Conference on Computing Education Research*. ACM, 8 pages.

[5] Brinda, T. and Terjung, T. 2017. A Database is Like a Dresser With Lots of Sorted Drawers: Secondary School Learners' Conceptions of Relational Databases. In *Proceedings of the 12th Workshop on Primary and Secondary Computing Education*, E. Barendsen and P. Hubwieser (Eds.). ACM, Nijmegen, Netherlands, 39-48.

[6] Diethelm, I., Hubwieser, P. and Klaus, R. 2012. Students, teachers and phenomena: Educational reconstruction for computer science education. In *Proceedings of the 12th Koli Calling International Conference on Computing Education Research*. ACM, 164-173.

[7] Diethelm, I., Wilken, H. and Zumbrägel, S. 2012. An investigation of secondary school students' conceptions on how the internet works. In *Proceedings of the 12th Koli Calling International Conference on Computing Education Research*. ACM, 67-73.

[8] Dinet, J. and Kitajima, M. 2011. Draw me the Web: impact of mental model of the web on information search performance of young users. In *The 23rd Conference on l'Interaction Homme-Machine*. ACM, 7 pages.

[9] DiSessa, A. A. 2014. A history of conceptual change research: Threads and fault lines. In *The Cambridge Handbook of the Learning Sciences: Second Edition*, R. K. Sawyer (Eds.). Cambridge University Press, 88-108.

[10] DiSessa, A. A. 1993. Toward an epistemology of physics. *Cognition and Instruction*, 10, 2-3, 105-225.

[11] Dole, J. A. and Sinatra, G. M. 1998. Reconceptalizing change in the cognitive construction of knowledge. *Educational Psychologist*, 33, 2-3, 109-128.

[12] Duit, R., Gropengiesser, H., Kattmann, U., Komorek, M. and Parchmann, I. 2012. The model of educational reconstruction–A framework for improving teaching and learning science. In *Science education research and practice in Europe*. Sense Publishers, 13-37.

[13] EUKidsOnline. 2018. *EU Kids Online IV - Reports: Children and adolescents on the internet. (As of December 2018, only Italian and Czech reports were available to us from the most recent wave.)*. http://www.lse.ac.uk/media-and-communications/assets/documents/research/eu-kids-online/reports/Executive-summary-Italy-june-2018.pdf; https://irtis.muni.cz/media/3115505/eu_kids_online_report.pdf. (Accessed: June 3 2019)

[14] Fraillon, J., Ainley, J., Schulz, W. and Friedman, T. 2014. *Preparing for life in a digital age: The IEA International Computer and Information Literacy Study international report.* Springer & International Association for the Evaluation of Educational Achievement (IEA).

[15] Grover, S., Rutstein, D. and Snow, E. 2016. What Is A Computer: What do Secondary School Students Think? In *Proceedings of the 47th ACM Technical symposium on computing science education*. ACM, 564-569.

[16] Hubwieser, P., Giannakos, M. N., Berges, M., Brinda, T., Diethelm, I., Magenheim, J., Pal, Y., Jackova, J. and Jasute, E. 2015. A global snapshot of computer science education in K-12 schools. In *Proceedings of the 2015 ITiCSE on Working Group Reports*. ACM, 65-83.

[17] Javora, O., Hannemann, T., Stárková, T., Volná, K. and Brom, C. 2019. Children like it more but don't learn more: Effects of esthetic visual design in educational games. *British Journal of Educational Technology*, 50, 4, 1942-1960.

[18] Kafai, Y. B. 2008. Understanding virtual epidemics: Children's folk conceptions of a computer virus. *Journal of Science Education and Technology*, 17, 6, 523-529.

[19] Lister, R. 2016. Toward a developmental epistemology of computer programming. In *Proceedings of the 11th Workshop in primary and secondary computing education*. ACM, 5-16.

[20] Mayer, R. E. 2009. *Multimedia Learning.* Cambridge University Press.

[21] McCartney, R. and Tenenberg, J. 2014. Special Issue on Computing Education in (K-12) Schools. *ACM Transactions on Computing Education (TOCE)*, 14, 2.

[22] OECD. 2015. *Students, Computers and Learning.* PISA, OECD Publishing.

[23] Özdemir, G. and Clark, D. B. 2007. An Overview of Conceptual Change Theories. *Eurasia Journal of Mathematics, Science & Technology Education*, 3, 4, 351-361.

[24] Papastergiou, M. 2005. Students' mental models of the Internet and their didactical exploitation in informatics education. *Education and Information Technologies*, 10, 4, 341-360.

[25] Robertson, J., Manches, A. and Pain, H. 2017. "It's Like a Giant Brain With a Keyboard": Children's Understandings About How Computers Work. *Childhood Education*, 93, 4, 338-345.

[26] Rücker, M. T. and Pinkwart, N. 2016. Review and discussion of children's conceptions of computers. *Journal of Science Education and Technology*, 25, 2, 274-283.

[27] Sorva, J. 2012. *Visual program simulation in introductory programming education*. Ph.D. thesis, Aalto University, Aalto University publication series.

[28] TheRoyalSociety *After the reboot: computing education in UK schools*. The Royal Society, City, 2017.

[29] Xinogalos, S. 2015. Object-oriented design and programming: an investigation of novices' conceptions on objects and classes. *ACM Transactions on Computing Education (TOCE)*, 15, 3, Art. No. 13.