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Publication date
2023

Document Version
Final published version

Published in
Croatian Society for Information, Communication and Electronic Technology – MIPRO

IEEE

mipro 2023

ISSN 1847-3946

organizer upro

46th

ICT and Electronics Convention

May 22 - 26, 2023 Opatija, Croatia

Lampadem tradere

mipro - innovative promotional partnership

mipro proceedings

MIPRO 2023

46th ICT and Electronics Convention

May 22 – 26, 2023
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Edited by:
Karolj Skala

Stimulating (Open) Data Literacy at the Basis of Society: Approaches for Active Learning and Teaching to Young Children

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***Abstract* - Children in the primary educational level learn about fundamental reading, writing and mathematics skills as a basis for future learning. In some European Union countries, they are also taught basic informatics and computer usage. However, only a few efforts are made to start teaching them about (open) data literacy. When teaching about data, multiple stages of the data value chain can be tackled, adapted to children's capabilities; from data production or collection to data usage or impact. Such teaching can be more theoretical, with already prepared examples, or a complete hands-on experience, where the data is collected from the environment, further analyzed, visualized and the conclusions about data are made. In this paper, we will present the currently available research on the approaches to teaching children about data. We will also discuss the potential benefits and the main issues impeding such an effort. Finally, we will propose the way forward for informal active learning about data for lower-level primary school children, based on the hands-on workshops using environmental data.**

Keywords – education; (open) data; data literacy; children; ISCED level 1

I. Introduction

Digital literacy is commonly recognized as essential for today's and our future societies. The digital literacy strategy of the European Union [1] announced and introduced "Strengthening Skills Intelligence" and "Increasing STEM graduates, fostering entrepreneurial and transversal skills" as two of the twelve actions in the skills revolution that is needed "to ensure people can thrive in the green and digital transitions, and to help in the recovery from the coronavirus pandemic" [2].

As a next step, the Digital Education Action Plan [3] was developed to support Europe's "Digital Skills for All" ambition. The Action Plan aims to "support the development of robust digital competences and organizational capabilities in education and training systems while fully harnessing the potential of emerging technologies, data, content, tools and platforms to make education and training fit for the digital age". Data literacy is a key element of digital literacy. It focuses on both the technical and social aspects of data. Data literacy encompasses activities related to data management, including data collection, data storage, data processing, data visualization, data quality, data dissemination and data use [4].

However, despite the increasing role of data in our lives, and the ambitions of the European Union to advance basic data skills at all levels, from early childhood to elderly, data education in primary and secondary school levels is underdeveloped, if developed at all. Known barriers to introduce data education are teachers' lack of technical expertise, teachers' lack of understanding of (open) data, and lack of understanding of how to integrate (open) data sets in school subjects (see [5], [6]).

According to the standard framework for categorizing cross-nationally comparable education statistics, primary education is classified in the International Standard Classification of Education (ISCED) Level 1 [7]. This type of education (also called elementary or basic education) typically starts at the age of 5-7 years and lasts for six years. ISCED level 1 education programs are typically designed to provide pupils with basic reading, writing, and mathematics skills that for the foundation for further learning. Other subjects such as history, geography, natural science, social sciences, art and music are acknowledged as fundamental and should be taught at this level [7].

In this paper, we aim to present a first step towards promoting data literacy of pupils taking part in the primary education (ISCED level 1). Most particularly the emphasis is on the lower-level primary school education, the first three grades (age 5-8 year). We will present the currently available research on the approaches to teaching children about data. We will also discuss the potential benefits and the main issues impeding such an effort. Finally, we will propose the way forward for informal active learning about data for lower-level primary school children, based on the hands-on workshops using environmental data.

II. Literature Review

A. Teaching general data literacy to lower-level primary school children

Data literacy is closely related to and dependent on other informatics skills and competences, especially those of digital literacy [8]. The European Commission (see [8],

p. 22) identified ten core learning areas of informatics in primary and secondary education: 1. Data and information, 2. Algorithms, 3. Programming, 4. Computing systems, 5. Networks, 6. People–system interface, 7. Design and development, 8. Modelling and simulation, 9. Awareness and empowerment, and 10. Safety and security.

Here, we focus on the data and information category. The European Commission report does not specify any categories of data and information skill's categories. Rather it provides example learning outcomes on data and information on different levels of education (primary and secondary school school levels). Applying the six cognitive learning levels in the Bloom's taxonomy (1. Remember, 2. Understand, 3. Apply, 4. Analyze, 5. Evaluate, 6. Create) to the European Commission report we see that the focus in primary school data and information education in some European countries is at the lower Bloom levels. For example, in the Czech Republic, pupils in primary school need to understand "the flow of information from its generation, storage on a medium, transfer, processing, retrieval by search and practical use", and in Slovenia they "should understand the binary system for representing data and know that the data can be compressed lossless and with loss of information". Only one example was provided for the lower primary school level (in Poland): "the learner lists the risks associated with widespread access to technology and to information and describes ways of avoiding them. The learner recognizes and respects the right to privacy of data and information and the right to intellectual property."

Research on data/information education in the lower levels of primary schools is scant. Some lessons may be learned from the almost as scarce research on data/information education in the higher level of primary school (grade 5 and up) [9]. For these groups, Saddiqua et al. [5] highlighted the importance of using up-to-date data or preferably hands-on experiences with data collection to better understand the concept of data, and how to use (open) data. Hands-on experiences would entail having the pupils collect and interpret the data themselves. In this respect, Saddiqa et al. [10] added that the data activities should be related to the world of the pupils. One may think of exercises about the pupils' height, the color of their eyes and generating some basic statistics about the collected data (average, mean, etc.). They also found that data education should focus on local, easy to recognize, situations such as measuring the height of a tower next to the school or counting how many cars pass their school. They also found that "simple open data visualizations representing students' municipalities captured their attention and encouraged discussions and reflections. These include topics such as water quality, forests, crimes, pollution sources, traffic, plastic pollution, lakes (locations, length, etc.)". Finally, in another study of the same authors they refer to the majority of teachers in the study that argue that pupils can develop basic data handling skills if they work with small datasets [11].

In addition to the type of learning activity research also identified prerequisites/issues for successful data/ information education. Some of those issues are at the education providers/teachers' side (limited data/technology skills). They may, for example, not be familiar with data cleaning and preparing concepts. Practical issues such as limited access to data, dataset language (not in native language e.g., Croatian), and the dataset size being too large to process by the teacher's laptop are mentioned as well as the need for an interface tailored to educational purposes.

Finally, Olsen [12] researched adapting a data literacy game to teach data literacy, initially intended for children aged 10-12, to children aged 8-10. To better suit younger children, one needs to be very careful in copy pasting educational methods of higher education to lower levels. This conclusion may also apply to the above: best practices on higher primary school levels may not necessarily apply to lower primary school levels.

However, one domain developed and implemented data/information learning outcomes for lower levels of primary school: the domain of (geo)spatial data.

B. Teaching (geo)spatial data to lower-level primary school children

Spatial data is any type of data that describes different instances through space and time. Spatial can refer to the study of any type of features be it outer space, the world, the spatial layout of the human body, the spatial layout of a room. *Geospatial data* is a term used to describe data about objects, events, or phenomena that directly or indirectly references a specific geographical area or location on the surface of the Earth, but the terms spatial and geospatial are often used interchangeably.

Spatial literacy is a fundamental form of literacy and refers to the ability to use the properties of space to communicate, reason, and solve problems. When examining geographic and environmental scale, spatial literacy is referred to as *geospatial literacy* to identify the spatial subset and scale under consideration.

Following the definition and use of the term literacy in an educational context, geospatial literacy refers to the mix of knowledge, skills, and dispositions required to communicate and understand geospatial information through representation [13]. Geospatial literacy is the key to transforming geospatial data into information and then into personal knowledge that can be used to make decisions, empower, ask broader questions, communicate, and report to society.

There is growing recognition that spatial literacy is important for mastering STEM content. The U.S. National Research Council [14] has found that spatial reasoning, a key component of spatial literacy, "…is at the heart of many great discoveries in science. It underpins many of the activities of the modern workforce, and it pervades the everyday activities of modern life". Indeed, spatial skills in childhood have been associated with success in several STEM fields [15], including engineering, chemistry, medicine, physics, geology, and computer programming.

Several recent studies (e.g., [16], [17]) have found that spatial skills are malleable and can be improved through early training, which is especially beneficial for children in the primary educational level. Early spatial skills training that includes interactive components such as hands-on exploration and feedback from the environment (e.g., visual cues) is thought to have positive effects [18].

The National Research Council [14], referred to spatial reasoning as a “missing link” in the (primary) school curriculum. The report stated that a “concerted effort to better integrate spatial thinking and bring it into schools could enable students to engage with their learning at a deeper level and also help to raise a new generation of spatially literate students”. Increasingly, demands for spatial literacy are being incorporated into education efforts in the UK, the US, and Australia [19].

In terms of classroom-based hands-on spatial training, a literature search revealed many suggestions for how educators can "spatialize" their teaching in the primary educational level. Spatializing mathematics curriculum, for example, includes adapting geometry lessons to include dynamic visualizations that incorporate 2D and 3D shapes [20]. Pupils can practice spatial reasoning from 2D to 3D spatial thinking by constructing 3D geometric figures out of paper. Simply drawing a flat sketch of a 3D object, such as a box, pencil, or chair, trains spatial thinking.

As part of geography curricula, map reading and navigation are great ways to train spatial skills. For example, by creating models and maps of their classroom, school, and/or community, pupils use these skills to deepen their knowledge of ecological, physical, and human systems and to develop a sense of place [21], [22]. Pupils of all ages can engage in treasure hunt activities, where they use a map of their school backyard (provided by the teacher or created by the pupils) to find hidden treasure. As with map skills, aerial and satellite imagery can be effectively used in classroom-based spatial training to help pupils in visualizing the physical or human phenomena that is present [23].

A geographic information system (GIS) is also a useful resource for developing pupils' spatial literacy, helping them navigate locally and globally, and combining data sets to identify relationships between them [24]. Although there is a general perception that GIS should be taught in the upper grades due to the more technical aspects of spatial modelling, there are systems that are accessible to pupils at the primary educational level. For example, an interactive website ‘Linsey the GIS Professional’ [25] teaches young children how to collect geospatial data and create a map of a park and builds children's spatial analysis and critical thinking skills.

C. Data literacy educational resources aimed at lower-level primary school children

Over the years, there have been attempts to involve children in data literacy with the help of various activities, both offline and online. A small handful of websites exist offering different approaches of teaching data to kids. Here we will present several examples and focus on the type of activity offered.

Kids in data [26] is a learning platform that teaches young children basic data concepts. The recommended age range is not specified, but the target audience is referred to as "the young children". The data used is the children's own data, generated by playing the game "Space Invaders": number of games played, score, ranking, etc. The platform serves as the basis for workshops in which children come together, play the game, and then analyze their own game data using a special online data visualization tool that was initially an open-source solution, but is now a paid service. In addition, the website includes short learning modules that teach kids the basics of data theory, such as the difference between quantitative and qualitative data, or the concepts of tables and charts (bar, line, and pie charts). While the website still works, it is not updated since 2020, and most theoretical content is missing with the “Coming soon” message. The website offers a very interesting idea, data gathering through joint game-playing. However, it would be better if the data visualizations and manipulations were provided directly in the web application, without the need to download data and use specialized (commercial) applications.

DIY Data Art: Creative data literacy for public libraries [27] is a set of “short self-guided activities that use personal data as an entry point to data science”, aimed to youth. The simple, yet highly engaging online and offline activities tackle particular data examples, such as network usage of their mobile phone applications, using emojis for visualization, exploring networks of connected people, exploring the community buildings in the neighborhood, etc. The activities are described in the Toolkit & Activity guide, which includes more examples, modifications and ideas.

A fresh squeeze on data [28] is a set of resources, including a free children's book and lesson plans, to teach young children how data is the basis for many problem-solving activities and life decisions, including the professional ones. Resources include introductions to data gathering, data analysis, data bias, etc. The available activities in the lesson plan are targeted to 3rd-5th grade of primary education.

Tableau Data Kids [29] is an educational program from the commercial data analytics and visualization web platform, Tableau. Their program for kids includes a variety of activities, including a full “Data Kids Educator Kit” with lesson plans intended for children ages 6-13. The demonstrations are made in the Tableau Public [30], a free platform to explore, create, and publicly share data visualizations online. Depending on the activity, data is obtained either from external sources (Spotify songs, Pokemon rules, etc.), from children surveying others, or from children’s own experience (favorite songs, the speed of room cleaning depending on the “messy” level, the number of toy bricks grouped by color, simple statistics of sprouting seeded vegetables, etc.). Data manipulation and visualization can be done both on paper or at the computer, in spreadsheet software and specialized applications. Often the emoji symbols are extensively used in different contexts and lesson plans.

Web platform **Youcubed** [31], provided by Stanford Graduate School of Education offers a set of resources for learning and teaching data science for different ages, from elementary school to high school students. The lessons include a community data collection project for engaging children with “citizen science” [32] or an elementary school outdoor activity “Data Tells Us about Ourselves” [33]. Extensive lesson plans for teachers are provided.

DataBasic.io [34] is a set of web tools that introduce data concepts to pupils of age 12+. The four available tools focus on finding the most used words and phrases, analyzing the data in a CSV file, showing the similarity of text files and analyzing the networks of connected data. Each tool contains the activity guide for teachers, several example data sources, and the possibility to import the custom data.

III. Lessons learned

Several lessons can be learned from our primary and secondary source literature review. The first lesson is that it is very well possible to teach ‘data’ to lower-level primary school pupils. However, there are clearly a number of aspects that must be considered in order to make it a success. For example, our study shows that data education should be connected to the children's world. Data activities that relate to the canal next door, the street around the corner, or the pupil's home are much more engaging to pupils than activities at a general level such as a city or country. The literature review also reveals that to be effective pupils should collect and interpret the data themselves: they should have hands-on experience with the tools and the data. They can create their own map of their surroundings, collect data about the number of cars in their street, or generate the average length of pupils in their class.

More advanced activities may include using a GIS to integrate collected data (number of cars per street) with existing base layers (aerial imagery or topographic maps) and perform basic spatial analysis of the data, creating new information (e.g., insight in car density per street) and visualizing this. If it is not possible for pupils to collect the data themselves, at least up-to-date data should be used. Another take away is (serious) gamification. This can be an effective strategy for our target group. For example, go for a geo treasure hunt (using GPS device to find the treasure), or have them analyze their own behavior for example on the time spent on playing a computer game, or map and analyze their route from home to school. For a sustainable approach to this type of teaching, we recommend the use of open data and open educational resources in the classroom, otherwise it is possible that the data or resources will soon become legally or technically unusable or obsolete.

In addition to the lessons learned for what and how to teach data to pupils at lower-level primary schools, also attention should be paid to the teachers: they need to be trained in data skills and equipped with sufficient user-friendly support systems so they can easily access up-to-date data and tools/apps, but also to share the data they collect and new insights from the data with the rest of the world (e.g., by connecting to citizen science platforms).

IV. Outlook towards a new approach for data education for young children

Based on the literature review on formal and informal ways to teach children (open) data skills, we propose a new approach for lower primary school children. In it, we aim to address all stages of the data value chain, from data production/collection to data use, adapted to children's abilities. We propose to prepare a set of workshops with a hands-on approach where children collect data from their local environment, analyze it, visualize the data, and draw conclusions based on the data, ask further questions, or think about the future possible extensions. In doing so, they would need to think critically not only about the data they collect, but also about the methods and conclusions. Although this may seem overwhelming at first for children at such an early age, we argue that this approach is feasible and that young children would gain the basic introduction to the key stages of the data value chain and improve their data literacy. The approach would include both offline and "online" activities, starting with various pen-and-paper approaches to arrive at initial findings about data without technical issues, but quickly moving to data literacy in the digital world.

The workshop topics relate to the children’s world, but also involve their relation to the environment. Examples of such topics would be:

- counting the things in their environment (how many cars or bicycles pass in the street)
- mapping their environment (where are the benches in the park)
- measuring the noise levels in different areas near the school
- reporting on the plants found in the neighborhood
- collecting data from children's own lives – time they spend doing certain tasks, data about their daily habits, etc.

Depending on the workshop type, it is also possible to introduce more data sources or environment properties to find possible relations, such as whether the number of cars is higher and the number of bicycles is lower on a rainy day than on a sunny day. Also, a part of the workshops would have the (geo)spatial component, where the visualizations would be made on a map, from the geocoded data collected.

Each workshop should – at least partially, depending on the topic – enable children to go through the following phases (Figure 1):

Data collection – the main data source should be obtained by the children, from the environment, from their own daily lives, or from making the basic surveys with the other people. Depending on the context and the type of data source, children can use pen and paper, mobile phones, or some other devices. Various applications can help them in data collecting, starting from the basic ones such as data timers, thing counters, text editors to more advanced ones, such as sound recorders, camera apps, noise measuring tools, geotagging apps.

Data processing – the data obtained needs to be imported to an application, checked for possible errors and cleansed if needed. In most cases, if the data is obtained manually (e.g., counting, surveying) children need to understand the point of data processing. This can be done in workshops where the data is gathered using other methods and apps. For this step, we should ensure that the data export from the device to the application is done automatically and as simple as possible, so that neither the teachers nor children have additional technical issues to solve, besides the ones that directly impact our learning outcomes.

Data analysis – after the data is imported and presented in some “children-readable” form, a simple data analysis

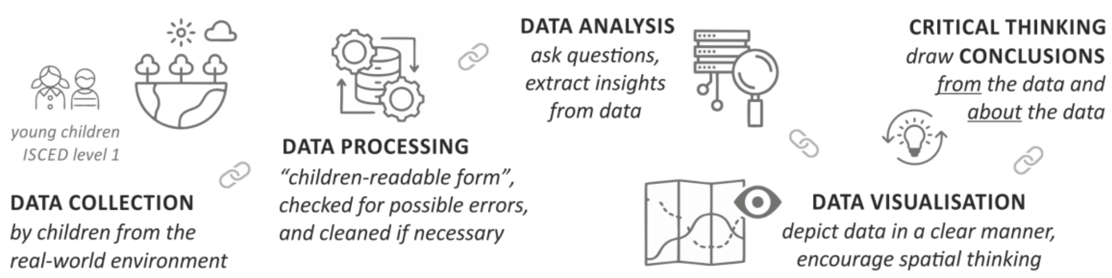

Figure 1. Data value chain approach to teaching (open) data literacy.
Adapted to children's abilities, key stages can be approached – from data collection to data use or impact

can be performed: finding averages, minimum, maximum, asking questions about what could be found out from the data, etc.

Data visualization – along with the data analysis, data visualization helps children to understand the raw data and draw conclusions in the next step. The visualizations should be clear and accessible to as many children possible. The way data is visualized is especially important for geospatial workshops, where data is visualized on maps, to help them improve their spatial thinking.

Conclusions based on data – after the basic data analysis and visualizations are performed, we'd like to engage in a more in-depth step: drawing conclusions not only from the data, but also about the data. Our goal is to try to engage pupils in critical thinking about the data – how was it obtained, were there some errors, why is the data different, how else they could have approached the task of data gathering and analysis. This step is one of the highest-ranked in Bloom's taxonomy of learning outcomes, but we feel it should be tried out with as much effort as possible, depending on the workshop type and pupils' characteristics, as it would also gain the most benefits, if successful.

From a practical view, one may think of a first series where the basic data skills are trained for each step in the data chain (Bloom level: remember and understand), followed by series that cover higher levels of Bloom, up to the design/create level. An alternative may be to educate the basic skills for the first step of the chain (understanding data collection), then do the data processing step at the Bloom level of apply and analyze, and the evaluate and design level of Bloom for the data visualization step.

The educational resources developed for running the workshops should be:

(i) extensive – teachers should be able to obtain the full and detailed versions of lesson plans / activity guides, which could be followed without the need for improvisation. These should in particular include the instructions for data gathering, the technical instructions for data manipulation, the methods for data visualization, and place an emphasis on the tools/applications needed to perform these tasks in the digital world.

(ii) ready to use – in order to facilitate the teachers in running the workshops, any content which might be of use during the workshop should be provided in a reusable manner before the workshop. For example, any sort of examples, demos, template sheets, etc. should be ready in advance, to leave the teachers worry-free as much as possible.

(iii) pedagogically sound – the workshop resources should – besides practical and technical instructions – provide the full set of pedagogical goals and methods, such as the learning outcomes based on Bloom's taxonomy, with higher levels of the taxonomy included.

(iv) up-to-date and published under an open license – in order to ensure the sustainability of the educational content provided, but also to provide flexibility for teachers to adapt the workshops as needed, any instructions or lesson plans should be published under the open license, such as Creative Commons, with as open version as possible. The best option would be to publish them under CC BY license, which retains the authorship, but allows free adaptations and commercial use. In case some example dataset is used (although our goal is to create/obtain the dataset at the beginning of each workshop), it should always be up-to-date, having timely and accurate data, to provide for decent conclusions.

(v) accessible and created with the universal design in mind – as the workshops should be accessible and inclusive for most of the children, they should be designed universally, respecting the principles of "universal design" and accessibility guidelines as much as possible. This includes the color schemes of graphs, large text, high contrast, simple instructions, different content formats, etc.

V. Conclusion

In this paper, we presented a first step towards promoting data literacy of pupils taking part in the International Standard Classification of Education (ISCED) level 1: primary education. Although there is limited research available on data education for 5-7 years old pupils, the currently available research on the approaches to teaching children about data reveals that it is very well possible to teach 'data' to lower-level primary school pupils. There is clearly a number of aspects that need to be taken into account in order to make it a success: (1) data education should be connected to the world of the children, (2) pupils should collect and interpret the data themselves: hands on experience with the tools and the data, and (3) use up-to-date data. To be effective, teachers must also be trained in data skills and equipped with sufficient user-friendly support systems to provide the data education that is urgently needed in our lower-level primary school systems in Europe.

For data education for lower-level primary school we propose a data education approach that builds on the concept of the data value chain. We propose to prepare a series of workshops with a hands-on approach, where the children would collect the data from their local environment, analyze it, visualize the data, and reflect on the results. In this way our approach contributes to the development of a data education approach for ISCED level 1 pupils that is needed to fulfil the ambition of the European Union to advance basic data skills at all educational levels, including those at lower-level primary schools.

ACKNOWLEDGMENT

This work was supported by the EU Horizon2020 project Twinning Open Data Operational 2019-2022 (Grant Agreement no. 857592).

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