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Integrating Engineering Principles in Data Literacy Workshops for Primary Education

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Abstract—Data literacy is an essential skill in today’s and future world. Children should be introduced to data literacy concepts in ways appropriate to their age, using real-world data examples and hands-on experiences. As part of the Erasmus+ DIRECTORS project, three workshops (each having two sessions) for children aged 8-10 (ISCED level 1) are currently being developed and implemented in selected primary schools in Croatia and the Netherlands. The first cycle of workshops was completed in November 2024, and the workshops – together with accompanying open educational resources – are now being improved for the final implementation in April 2025. This paper focuses on the engineering principles “hidden” in our DIRECTORS data literacy workshops. While we primarily emphasize data literacy and digital skills, engineering elements are intertwined throughout our whole program and in all data life-cycle phases: collection, processing, analysis, visualization, as well as critical thinking, and drawing conclusions. We give an overview of the engineering principles present in data life-cycle phases of each workshop. We describe which activities were used to implement them, and we discuss the importance of each principle in our workshops, making small steps to a more successful, albeit somewhat “hidden”, engineering education.

Keywords—data literacy, digital skills, primary education, hands-on activities, engineering education, Erasmus+ Project DIRECTORS

I. INTRODUCTION

Education in the modern world often emphasizes the need for children to become fluent in STEM (*Science, Technology, Engineering and Math*) fields, as these are considered to be the building blocks for future professions. Closely related to these terms stands the term “data literacy” which includes, inter alia, “the ability to understand, find, collect, interpret, visualize, and support arguments using quantitative and qualitative data” [1]. While data literacy can be taught “as is” (using data skills framework such as [2]), it seems beneficial to see whether “pure” data literacy education can also be considered as “hidden” engineering education, where some concepts or principles important for future engineers could be intertwined. Some examples of recognizing such a need can be found in [3], [4]. The goal of this paper is to unearth the engineering concepts in our data literacy workshops.

As a small step in improving data literacy of children in ISCED 1 primary education level (ages 8-10), the Erasmus+ project “DIgital data-dRiven EduCaTion fOR kids” (DIRECTORS) started in December 2023. This

“*Small-scale partnerships in school education*” project is carried out by the University of Zagreb’s Faculty of Geodesy and Faculty of Electrical Engineering and Computing and Delft University of Technology’s Faculty of Architecture and The Built Environment. The project is oriented towards creating open educational resources, in the form of adaptable workshops, to be used – in whole or partially – whether in a usual class setting or as separate events. To evaluate our teaching approach and materials, during the project, we also implemented these workshops in selected primary schools in Croatia and the Netherlands.

The workshops are designed with the whole data life-cycle in mind. This means that we do not solely focus on one part of data literacy, such as data visualization (which is probably the most popular topic to tackle); instead, we tackle many topics throughout all data life cycle phases, from *data collection, data processing, data analysis, data visualization, to critical thinking about data and data supported decision making*. We also include additional topics such as privacy/anonymization, data quality or relation to specific engineering fields such as geodesy and cartography. We find it important to work with real data sources that children can use to obtain the data instead of datasets prepared in advance or “imaginary” data. This motivates children in additional ways and provides a whole set of new questions – sometimes issues as well – which can arise but are very important to discuss with children. We also try to show the same or similar concepts first in an analog context and then in the digital context to show the children different methods of data usage and to critically discuss whether technology is always the best, most precise, and most efficient solution.

While our workshops might not be considered as usual STEM workshops, we have intertwined several engineering principles in various workshop activities. We consider such indirectly gained knowledge and engineering experience a valuable asset for children’s development and impact on their future.

This paper presents our workshops and intertwined engineering approaches in different data cycle phases. In Section 2, we shortly present our six workshop sessions. In Section 3, we describe the data life cycle and, in particular, engineering principles in each phase with examples of the activities supporting them. In Section 4, we discuss our experiences and selected parts of evaluation dealing with engineering principles. Section 5 concludes the paper with our future work.

II. WORKSHOPS OVERVIEW

The data literacy workshops, developed during this project consist of three workshops, each having two sessions, with each session lasting 60-90 minutes. The workshops are suitable for children aged 8-10 (ISCED level 1), were developed with different contexts in mind, and are easily adaptable to the childrens' age, school context, or times available.

Below, we provide a short description of the workshops, as is given in the official DIRECTORS project leaflet, available at the project webpage [5]. Additional information about the workshop implementations can be found in workshop implementation news [5] and in [6].

A. Workshop 1: Data in our Hands (and Mobile Devices)

The first workshop will introduce the pupils to the world of real-life data, from data collection to processing and critically evaluating results. Pupils will explore real-world data by looking at their own use of mobile devices – for example, their favorite games or video channels, the amount of time spent on a particular app, and so on. During the first session, they will estimate their use of mobile devices and create data cards with their estimates and favorite apps. They will then learn how to group, categorize, and how to clean data to visualize in a word cloud. In the second session, pupils will learn how to collect, adapt, and enter actual mobile phone data into a dataset. They will investigate similarities and differences between the entire class's data and their own data and compare their estimates to the data they have collected. They will also learn how to visualize real-world data, why it is important for data to be entered accurately, and how to preserve privacy when adding personal information to a shared dataset.

B. Workshop 2: Geospatial Data (and Maps) in Our Hands

The second workshop will introduce the pupils to the world of geo-information and geospatial data mapping. In the first session, they will become familiar with the basics of Geographic Information Systems (GIS) by creating map layers on transparent sheets and mapping the school's surroundings. Each sheet will represent a single layer of information, such as buildings, trees, roads, or playgrounds. When these sheets are placed on top of each other, all the layers are combined into a complete map, serving as a simple visual analogy for GIS. In the same way, the sheets show the different layers GIS systems digitally organize and analyze data in layers, allowing for viewing and exploring various spatial elements. In the second session, pupils will apply their newly acquired knowledge in a digital environment by participating in a detective-themed treasure hunt. Step by step, they will solve puzzles using GIS layers and data in a digital form. The detective game will conclude outside the school, following the geographic coordinates obtained by solving the puzzles.

C. Workshop 3: Data Sources

The third workshop will introduce the pupils to more advanced data skills: how to gather data from various real-world sources, assess data quality, and critically analyze the results obtained. This will be illustrated by the example of

counting steps and measuring and calculating distances in different ways. The data sources used will include manual counting, counting with mobile apps, counting with smartwatches/sports bands, measuring distance with Google Maps, and measuring distance using mobile phones with built-in GPS while recording GPX tracks. In the first session, pupils will explore the differences in step counting within the classroom using various methods and sensors, and how these results are used to calculate a distance. In the second session, we will move to the school playground, where pupils will measure a longer distance in multiple ways, including satellite-assisted devices. While walking, they will also record GPX tracks showing their walking route. Returning to the classroom, they will compare the results from all measurement methods and conclude that while technological solutions are important, we should not blindly trust technology and collected data without verification and further investigation.

III. ENGINEERING PRINCIPLES IN DATA LIFE-CYCLE

A. Data Life-cycle Description

In our workshops, we aim to lead the children to experience all stages of the data life-cycle. We introduce them to:

- i) *Data collection* – children collect the data from the real-world environment and create datasets;
- ii) *Data processing* – data is processed in a “children-readable form”, checked and cleaned;
- iii) *Data analysis* – children ask questions and get answers based on insights from the data;
- iv) *Data visualization* – children realize that data can be presented using different methods, which helps the analysis;
- v) *Critical thinking and drawing conclusions* – children draw conclusions not only from the data but also about the data and the data sources.

B. Engineering Principles Used in Workshop Activities

The workshops span across several topics, from basic data manipulation through geo-informatics and its “high-tech” concepts such as GPS, to data obtained through sensors. While all these topics are related to data, we argue that these can also be small steps to the world of engineering and its concepts. Depending on the engineering field, data can be of various types and exist in various contexts. We believe that most of these data-related concepts, experienced in child-friendly activities in our workshops, can be applied to most engineering disciplines, depending on the context. From these recurring ideas we distilled a set of engineering principles – an illustrative, not exhaustive, catalogue of widely recognized yet often implicit practices that surfaced during workshop design. Therefore, in Table 1 we present an overview of engineering (data-related) principles, applied in particular phases of the data life-cycle and their occurrence in our workshops. The workshops are marked with the workshop and session number (e.g. 3-1 as Workshop 3, session 1) for easier referring to lesson plans and other educational content, available on our webpage.

In the following paragraphs, we will briefly describe how these engineering principles are applied in our workshop activities, as seen in Figure 1. For brevity, the text is not exhaustive, as activities in different workshops change while the same or similar principles are applied.

(i) Making choices: This is one of the most important and needed things an engineer does. Children should learn to make informed choices based on the available arguments and goals needed to be accomplished. In our workshops, we decide which data should be gathered to answer our questions, how to gather data (analog or digital methods, which technology to use for collecting), do we need to transform the raw data into something else, which method to use for visualization/analysis (word clouds, different types of graphs); we also make choices about data quality (choosing the map scales) and show the consequences our choices have on the final output and our conclusions.

(ii) Creating versus collecting data from a real-world source: Engineers sometimes gather the data from the outside world, but in some cases, they also create the data themselves. Both are experienced through our activities, with different emphasis. We also point out that when dealing with real-world sources, children learn that data can be unpredictable and might need more processing than the „artificial“ data a person can make.

(iii) Using devices to collect data: Collecting data from the real world not only depends on unpredictable external data sources but also on the collection methods, which can also introduce errors based on their characteristics. We would like our young future engineers to become aware of that, so we expose them to simple methods of collection using devices but also use high-tech solutions and sensors, such as pedometer sensors in mobile phones and fitness trackers, or GPS technology in mobile phones, e.g., GPX tracks, for future analysis.

(iv) Estimating data: Engineers should be well-trained in making estimations, as a good estimation helps in initial problem definition towards a concrete solution. We ask children to estimate the data they will later collect (such as their mobile phone usage, steps taken, or distances of objects). Later, we evaluate their estimations and compare these with the real data obtained so that the children can draw conclusions of estimations versus reality.

(v) Categorizing and grouping data: Although categorizing might seem like something that adults do naturally, engineers categorize data all the time in a quality manner, as it is one of the building blocks of making solutions. In our workshops, we show children the importance of categorizing data that needs to be collected; we also have a number of categorization examples in the analysis phase, where they can experience categorization over multiple characteristics. This can be a huge help in making complex conclusions from basic data sources. Grouping is also often used in visualization, which is one of the childrens' favorite workshop experiences as they finally „see“ data.

(vi) Comparing and correlating data: After the data is categorized, it can be more usefully compared over one or more categories. The children experience the importance of comparisons over categories, of comparisons between their own results versus small groups, which might have things in

common (categorized over one variable but comparing others) versus global results of the whole class. We also compare data collected using different collection methods (analog, digital, different devices, etc.) to make conclusions. In one workshop, the children compare data from geo layers while constructing layered maps. Through more complex comparisons and analysis, they learn how correlation can be an important concept to make conclusions about data.

(vii) Differentiating data types and variables: Another basic skill for engineers dealing with any data is understanding data types. When collecting, processing and analyzing data, we teach the children that each data is of a particular type (string, number, time, distance, geodata...) and that each type has its own constraints intended for easier processing. This principle includes error handling and is related to data quality – see the example below.

(viii) Data changing over time and data history: In data handling, engineers understand that data changes over time, and data history can be important to make comparisons and conclusions. In the workshops, we invite children to check their history of mobile phone usage, and we discuss how to handle possible interesting questions such as differences in phone usage over weekends or working days, etc.

(ix) Evaluating data quality: One of the main engineering principles; if the available data is non-accurate, incorrect, outdated or not detailed enough, our calculations, analyses, conclusions based on such data would probably also be wrong. In the workshops, we see how errors in data input give wrong results (a nice visual example is the word cloud with wrongly typed names of favorite games), how layers of geodata must be precisely put over the map, how the choice of map scale influences problem solving or how using more detailed data brings us closer to the problem solution. We focus especially on data quality of measurements done by high-tech devices (mobile phones, fitness trackers, GPS), where we show that the results from different devices can differ vastly, but also that repetitive measurement of the same data on the same device does not exactly give the same results – either due to device characteristics or due to external factors. We consider this principle one of the most important assets of our workshop activities.

(x) Cleaning data: Whether data is obtained from the real-world or created by us, engineers need to clean the data before starting any analysis. In our workshops, we show how the childrens' incorrect typing (data input) can „mess up“ our analysis, how data values can be out-of-range or how map features (e.g. buildings, roads and landmarks) need to be cleaned and standardized first. As an example, we explain (based on real childrens' mistakes) that when they type the number 4 with letters FOUR, we cannot include this data in any calculations or graph; we have to clean it first.

(xi) Transforming data: Sometimes, data is not in a format suitable for our needs, and engineers need to transform data to be more adequate for some purpose. We show the children how raw data gathered can seem hard to analyze, and how transformations might help us to prepare for visualizations and analysis. In our workshops the children trace roads, buildings, and other features onto transparent overlays, mirroring how engineers extract precise geometric data from raster images. By transforming these elements into editable shapes, they discover that vectorization supports accurate

measurement, deeper spatial analysis, and seamless integration with other geospatial layers – key steps in a variety of engineering applications. In addition, we use another transformation type, georeferencing, that refers to anchoring data to real-world coordinates. In our workshops, the children align each transparent overlay using designated “cross” points corresponding to an underlying orthophoto map, thereby ensuring precise spatial alignment. Through this process, they observe how consistent reference points preserve positional accuracy, highlighting the significance of georeferencing for reliable measurement, in-depth analysis, and informed engineering decisions.

(xii) Abstracting data: By changing the level of details when viewing the data, we can focus on the whole picture of our problem or on a specific small section. We illustrate this concept when creating maps by layering geospatial data – a professional practice that allows distinct features (e.g., buildings, roads, vegetation) to be isolated or emphasized for clearer analysis and decision-making. In geodesy and geoinformatics, abstracting data often refers to handling scale and cartographic generalization. In our workshops, by comparing maps at different scales, we show our children that a small-scale map includes only major features, whereas a larger-scale map can capture finer details. By exploring these differences, they learn that engineers must carefully select the right scale and degree of generalization – simplifying or omitting certain features – so the map remains clear yet useful. This highlights how scale choices directly affect both accuracy and interpretability of geospatial data.

(xiii) Augmenting data: If engineers add more data from other sources to a dataset, such combination could provide even more results and deeper conclusions. We show this by enhancing maps with scale, orientation, symbolization, and legend to facilitate effective interpretation. We also augment the mobile usage data by adding new categories (e.g., types of favorite games, which were not included initially) and show new available analyses and answers.

(xiv) Narrowing the problem: Engineers use different approaches to solve complex problems, such as a Top-Down approach, or trying to isolate and narrow a large problem by dividing it into sub-problems small enough to be successfully solved. When playing the (Geo) Escape Room game, in each step, the children narrow their search for the missing teacher by using more detailed clues and map features. For example, they analyze spatial relationships among map elements (e.g., calculating distances, identifying clusters of features); they also utilize buffer creation and other GIS operations to explore the influence zones of various environmental features.

(xv) Synthesizing from data: Just having data is not a goal by itself; it is used by engineers as a help in problem solving. From data, we can synthesize the knowledge about the problem which is more than the sum of available data. In our workshops, we show that joint results of the whole group give more value than the data of each person; we use locations obtained from GPS to create walking tracks or measure distances, we vectorize images to make them available for GIS computations, which provide answers to our questions.

(xvi) Handling data scarcity: Engineers are often faced with lack of needed datasets that would help them answer their

questions; by discussing these issues with the children, seeing if they have related questions that cannot be answered by the available data, we motivate them to think about data collection (what can be collected and how) and also to find alternative ways to answer some of the questions.

(xvii) Calculating using data: Engineers are used to all sorts of calculations or computations, either manual or by using tools that do the heavy lifting. In the more advanced workshops, especially where devices are used as data sources, the children measure steps to measure distances, do routing, calculate averages and use other methodologies for measuring, etc. We also use approximation formulas (such as calculating the stride length from the person’s height) to show how data can be inferred with approximation.

(xviii) Anonymizing data: If the data contains personal information or it can be inferred, data should (depending on what needs to be done) be processed and anonymized. When filling out and analyzing an online poll, the children can discuss whether this data is fully anonymous, how it could be anonymized (or sometimes even de-anonymized), and especially why it should (or should not) be done. As children grow up, they should be aware of this, whether going in the engineering direction or not.

(xix) Data trust: Going hand-in-hand with data quality, an important question arises: can engineers trust data? Data quality deals with accidental errors or inaccuracies by design, etc. But, data can also be maliciously manipulated. We show that it is very easy to “cheat” the devices, for example waving hands instead of walking when “counting” steps with a device. A critical thinking attitude should always be present, and data should never be trusted blindly.

(xx) Data economics: In the end, a good engineer needs to evaluate “is it worth it”? Is it worth having a very sophisticated, precise, and expensive device to measure something (not that) important? Sometimes the answer is “yes”, sometimes “not so much”, and differentiating this is also an engineering principle. When we discuss our activities, especially the ones using technology, the children should always consider whether we needed, for example, a fitness tracker needed to measure just a few steps across the room, and was it even accurate in that scenario? Going back to the beginning of this section, good engineers know how to make good choices.

IV. DISCUSSION AND LESSONS LEARNED

Table 1 gives a broad overview of how the principles are distributed in workshops and data life-cycle phases. We can see that each workshop session contains at least one of the principles, sometimes more than a few. Also, it is important that the same principle can be found in the different phases and the different workshops. With the former, we reinforce learning by repeating the same engineering concept in multiple uses. With the latter, we offer the fullest experience, even in cases where children only attend one workshop. Of course, in an ideal and a bigger scale project, it would be best to have children participate in the complete set of workshops, thus gaining the fullest picture and experience on data literacy.

In terms of the particular data life-cycle phases, we can comment on the following:

TABLE I. AN OVERVIEW OF ENGINEERING PRINCIPLES IN DIRECTORS WORKSHOPS OVER DATA LIFE-CYCLE PHASES (NUMBER PAIRS INDICATE WORKSHOP-SESSION; E.G., 1-1 = WORKSHOP 1, SESSION 1)

	Data collection	Data processing	Data analysis	Data visualization	Critical thinking and drawing conclusions
i. Making choices	1-1,1-2,3-1,3-2				1-1,1-2,2-1,3-1,3-2
ii. Creating vs collecting data from a real-world source	1-1,1-2,2-1,2-2,3-1,3-2				
iii. Using devices to collect data	1-2,2-2,3-1,3-2				
iv. Estimating data	1-1,3-1	3-1	1-2		1-1
v. Categorizing and grouping data	1-1,1-2		1-1,1-2	1-1,1-2	
vi. Comparing and correlating data	2-1		1-1,3-1,3-2	1-1,1-2,2-2,3-1,3-2	
vii. Differentiating data types and variables	1-1,1-2				
viii. Data changing over time and data history	1-2				
ix. Evaluating data quality	2-1		2-2,3-1,3-2		1-1,1-2,2-1,2-2,3-1,3-2
x. Cleaning data		1-1,1-2,2-1,3-1,3-2			
xi. Transforming data	2-1	1-2,2-1	2-2		2-1
xii. Abstracting data	2-1	2-1			
xiii. Augmenting data		2-1	1-2	2-1	
xiv. Narrowing the problem		2-2			
xv. Synthesizing from data			1-1,1-2,2-1,2-2,3-1,3-2	1-1,1-2,3-1,3-2	2-1
xvi. Handling data scarcity			1-2		
xvii. Calculating using data			1-2,2-1,2-2,3-1,3-2		
xviii. Anonymizing data					1-2
xix. Trusting data					2-2,3-1,3-2
xx. Data economics					3-1,3-2



Figure 1. Panels arranged left-to-right illustrate the following activities: (a) data cleaning by fixing wrong input, (b) collecting data by vectorization, (c) using devices (smartwatch) to collect data and (d) evaluating data quality by comparing recorded GPX tracks

Data collection, being the first phase of every workshop, often going hand-in-hand with the workshop introductions, is a good place to introduce several principles. These are implemented as part of concrete activities where the children's effort is easily seen, which makes the implementation easier.

In *Data processing*, the most used principle is data cleaning. This is needed both for the next phases of the workshops (as we need the "clean" data to work with), but it is also very important that children see it being done or – even better – do it themselves.

In *Data analysis*, it is obvious that principles such as calculations, categorizations, comparisons, and synthesis take place. It is also a good point in time to introduce questions of data quality, as an analysis of low-quality data makes a bad analysis (*garbage in → garbage out*).

Data visualization tackles similar principles. In our workshops, it is hard to distinguish the visualization phase from the analysis phase, as the children would have a hard time dealing with long and complex analyses without "seeing" the results. So, we often intertwine those two phases during the same activities.

The last phase, *Critical thinking and drawing conclusions*, is surely the most complex to implement, for two reasons: first, if it is mostly done at the end, the children's concentration is low; second, being the most abstract one, it can be hard to get the whole class discuss such high-level topics. Therefore, we try to "critically think out loud" about these issues throughout the workshops, from the beginning. This also stimulates reiterative thinking.

Although it is the hardest to implement, the last phase should also be one of the most important for future engineers, in terms of "learning how to learn" and thinking about the concepts, not so much obtaining only the skills. So, our focus is on the principles of making choices, evaluating data quality, and trusting data. If the children would take home just the subset of things learned in these workshops, these principles should be the most important ones.

The official evaluation of the workshops implemented in the first cycle, for both children and teachers, is described in [6]. Here, we would just like to emphasize that evaluating complex concepts can be hard for young children (age 8, for instance). Their evaluation stays at the level of liking an activity or simple answers on „*What did you learn today?*“ – „*I learned to make a map*“. In Workshop 3, we can ask questions such as „*Which method of measuring was the best?*“ and „*Why?*“. Besides answers such as „*It was fun*“, the answers such as „*It was easier*“, „*It was more accurate*“, or „*It was funny when the fitness tracker measured wrongly*“ were also present. Even with children so young, they can at least start thinking about these engineering principles, which was one of our goals.

V. CONCLUSION

This short analysis gives an overview of selected engineering principles experienced or discussed during the phases of the data life-cycle, implemented in six workshops

of the DIRECTORS project. By focusing on real-world data and hands-on activities, these workshops encourage critical thinking and lay the groundwork for an early engineering mindset among children aged 8–10. In particular, the iterative process of collecting, cleaning, analyzing, and visualizing data helps them develop problem-solving skills, a deeper understanding of data quality, and awareness of technology's role in everyday contexts.

The results are based on the first cycle of workshop implementation, done in autumn 2024. The second cycle is being prepared in the moment of writing this paper, after the international evaluation performed by both Croatian and Dutch partners jointly. After the second cycle implementation, we will use our new experiences for the development of the final versions of educational resources. We plan to do a thorough analysis of the planned and performed activities in the workshop phases and to offer detailed lessons learned from our experiences.

Although a longitudinal approach – tracking the same group of children over a longer period – could offer a clearer view of how these workshops facilitate sustained growth in data literacy and engineering-oriented thinking, our initial findings already indicate the potential benefits of integrating engineering principles at this early stage. We hope our experiences and lessons learned will serve as a foundation for advancing both early engineering education and data literacy among younger primary school students.

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