# Personal Data Physicalization in focus: a classroom experience

**Isabel Harb Manssour**[1], **Milene Selbach Silveira**[1]

[1]Escola Politécnica
Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS)
Avenida Ipiranga, 6681 - Prédio 32 – 90619-900 – Porto Alegre – RS – Brazil

{isabel.manssour,milene.silveira}@pucrs.br

***Abstract.*** *We have transitioned from knowledge-based to competency-based learning in computing education in the last decades. When teaching computing subjects, we must design activities that instill dispositions (the "know-why") such as adaptability, collaboration, inventiveness, and many others. The use of active methodologies stands out in this scenario. In this work, we present a classroom experience in a Data Visualization course using the concept of data physicalization. We observed the students' engagement and the possibilities of promoting different dispositions, in addition to the content assimilation per se. We believe our lessons learned can help develop similar activities in data visualization education.*

***Resumo.*** *Nas últimas décadas, quando tratamos da Educação em Computação, fizemos uma transição de uma aprendizagem baseada no conhecimento para uma aprendizagem baseada em competências. Neste contexto, temos que promover atividades que promovam, dentre outros, a adaptabilidade, a colaboração e a "inventividade", o que destaca a necessidade de utilização de metodologias ativas. Neste trabalho, apresentamos um relato de experiência em sala de aula, em uma disciplina de Visualização de Dados, utilizando o conceito de fisicalização de dados. Nesta experiência, observamos vários aspectos, como o engajamento dos alunos, além da assimilação do conteúdo em si. Acreditamos que as lições aprendidas podem auxiliar no desenvolvimento de atividades similares na área de Educação em Visualização de Dados.*

## 1. Introduction

According to the ACM/IEEE Computing Curricula 2020 [Task Force 2020], since 2005, we have had several changes in the computing education world. One of the important changes is related to the transition from knowledge-based learning to competency-based learning. The report specifies competency as a composition of dimensions (Knowledge, Skills, and Disposition) observed during a Task performance. The combination of dimensions is fundamental for today's computing professionals.

Focusing on dispositions, they are elements of human behavior, including being adaptable, collaborative, inventive, meticulous, passionate, proactive, professional, purpose-driven, responsible, responsive, and self-directed [Task Force 2020]. This kind of element is not taught through conceptual explanations; it should be developed through different activities. And active methodologies stand out in this scenario.

Ribeiro and Passos [Ribeiro and Passos 2020] highlight the six active methodologies most used in Computer Science courses in the studies they analyzed: gamification, problem-based learning, project-based learning, peer instruction, flipped classroom, and team-based learning. Silveira [Silveira 2020] includes the use and/or development of games in the classroom environment.

In this work, we present a classroom experience in a Data Visualization course, categorized as a project and team-based learning. Using the concept of data physicalization, "a physical artifact whose geometry or material properties encode data" [Jansen et al. 2015], students construct personal data physicalization. We observed the students' engagement and the possibilities of promoting different dispositions, such as inventive, purpose-driven, and meticulous.

In the following sections, we present an overview of data physicalization, contextualize the course, and describe the conducted activity. We also provide a detailed description of the activity's application and the results obtained. Finally, we share lessons learned from the experience and present final considerations.

## 2. Data Physicalization

According to Jansen et al. [Jansen et al. 2015], data physicalization is "an emerging research area that uses physical data representations to help people explore and communicate data". In this context, physicalization refers to a physical artifact whose geometry or material properties encode data. Utilizing such tangible objects can enhance cognition, communication, learning, problem-solving, and decision-making. This approach allows the support of human-computer interaction through physical objects and the analysis of this data through visualization [Jansen et al. 2015].

Kirigami (a Japanese art form that uses paper cutting) [Daneshzand et al. 2022], 3D printed models, light, sound, or other sensory inputs can be used to convey information [Jansen et al. 2015]. However, Sauvé et al. [Sauvé et al. 2023] state that "designing physicalizations for real-world problems is non-trivial". Some of the challenges include the choice of materials and suitable data to represent through physicalizations. Other challenges are identifying tangible interaction techniques that can be used and how the final result can be valuated [Daneshzand et al. 2022, Jansen et al. 2015].

There are several initiatives in this area, with one example being the creation of customizable physical conference badges [Panagiotidou et al. 2020]. The use of personal data with data physicalization has also been investigated, both in information visualization courses [Perin 2021] and using narratives to broaden the understanding of data [Karyda et al. 2020]. A workshop was also recently proposed at CHI 2023 (Conference on Human Factors in Computing Systems) to unite researchers and practitioners with a common interest in utilizing data physicalizations to address real-world challenges. Finally, data physicalization outside the academy, in shopping malls and public spaces, is also observed. For instance, the SWAB International Contemporary Art Fair audience actively generated a physical parallel coordinate chart based on their profile and answers to simple questions[1].

Improving cognition and data communication are benefits of using data physicalization. Another advantage is to increase engagement, involving the audience, so that people explore and better understand the data represented there [Jansen et al. 2015].

[1] http://dataphys.org/list/data-strings-physical-parallel-coordinates/

Perin [Perin 2021], for example, presents the results of implementing Data Physicalization work in an information visualization discipline as positive, as it allowed students to learn the content through developing creative projects. Knudsen et al. [Knudsen et al. 2023], when exploring the use of Lego bricks to create physical data representations with a group of students, stated that the exercise helped students "construct and tear apart ideas, to deconstruct ideas" and that collaboration allowed them to discuss different ideas. These benefits justify the recent interest and growth of this research area.

## 3. Into the classroom: the context

This section contextualizes the course in which the active methodology was applied. It shares the insights obtained with previous applications, the task to be performed, and the profile of the participants.

### 3.1. The Course

The activity was conducted in a Data Science and Artificial Intelligence Undergraduate Program course. This Program encompasses theoretical and practical courses such as Calculus, Programming, Artificial Intelligence, and Deep Learning. These undergraduate course subjects are distributed over eight semesters. "Data Visualization" is a mandatory 4-credit course in the 5th semester. The classes for this course take place on Tuesdays and Thursdays, starting at 7:15 PM and concluding at 8:45 PM.

This course introduces data visualization and its applications, covering basic concepts, perception, data types, visual representations, and interaction principles. At the end of the course, students should know tools for data visualization and understand how to use visualization to analyze data from different applications, seeking solutions that help to interpret and present results. The adopted methodology includes theoretical, practical, and interactive classes employing active methodologies, seeking to empower students in constructing their own learning experiences. Dialogued expository classes are taught based on technical books, papers, and materials available on the Internet. Additionally, practical classes are conducted in the laboratory, encompassing case studies, exercises, and group dynamics.

Course enrollment occurs in the fifth semester, so students typically have a more mature profile. Most are already engaged in internships or employment. Additionally, as it is a recent Undergraduate Program (the first class of students joined at the beginning of 2021), class sizes remain relatively small, fostering a more conducive environment for meaningful dialogue.

### 3.2. The Activity: first insights

In the first semester of 2023, a data physicalization activity based on Perin's work [Perin 2021] was introduced on an experimental basis to a class of 19 students. This activity was proposed to help students learn about data visualization, foster the design of creative projects, and encourage active involvement. Three consecutive classes were used, and the activity was considered non-graded. The first class discussed the tasks to be undertaken (refer to Section 3.3), with students tasked with sourcing data, thinking about what to do, and selecting materials. To encourage student commitment to the activity, it was decided that there would be a vote to select the work demonstrating the best results. Some students worked in pairs, and others worked individually. The subsequent class was dedicated to preparing the data physicalization. The results were presented in a third class, and the vote was conducted among the students to determine the best work. At the end of the activity, a gift was awarded for the best work.

Based on our first experience with data physicalization in the classroom, we observed the need for improvements. First, it is important to give students more time to think about what they will do and collect data. Second, it would be better to use a space where the students could collaborate better and also store their work, as it is difficult to transport the work being created. Third, we observed that some students only execute activities if they are worth a grade.

We also noted that the classes facilitated more meaningful interaction and engagement among some students. Consequently, this classroom experience motivated further research on the topic, leading to the submission of a project to the ethics committee.

Thus, in the second semester, the activity was again conducted over three classes but with a distinct approach, considering the improvements identified in our first experience. Its statement was discussed two weeks prior, carried a graded assessment, and followed the Ethics and Research Committee protocol[2]. A detailed description of the tasks performed is presented in Section 3.3, and the profile of the participants is described in Section 3.4.

### 3.3. The Task

The steps followed in executing the activity are shown in Figure 1. The first consists of presenting the work statement. Following the idea of Perin's work [Perin 2021], students should:

- Collect personal data with a temporal component seeking to identify correlations and also formulating questions about data;
- Create physical representations of data, describing and justifying the choice of materials and visual variables.

Personal data is justified because we generate a lot of personal data nowadays, from exercise records to interactions on social networks. Visualization and Visual Analytics can help gain personal insights, promoting self-reflection and self-improvement [Huang et al. 2014, Daneshzand et al. 2022].


**Figure 1. Steps of the activity methodology.**

During the **activity explanation**, several examples of data physicalization and materials that could be used were showcased. These examples were collected

[2]CAAE number: 74391423.0.0000.5336

from literature in the area [Panagiotidou et al. 2020, Vladis et al. 2020, Perin 2021, Daneshzand et al. 2022] and from the internet as the textile data visualization from a Stanford course[3], "pyramids" sculptural from the earth's populations[4], the use of boxes to represent global population growth in a TED talk from Hans Rosling[5], and other examples from the data physicalization wiki[6].

Then, the students should engage in **data gathering** by collecting personal information for a week or two. The objective is to look for correlations or answer questions about this data, e.g., to identify behavior patterns. Smartwatch data, such as number of steps and sleep quality, appointment planner information (e.g., exams, work, and social activities), commits on GitHub, and ChatGPT queries are examples of data that could be collected.

They had two classes for **activity development** two weeks later. A set of materials was provided, such as scissors, glue, pins, clips, gouache paint and brush, modeling clay, post-its, ribbons, crochet threads, pens, toothpicks, matches, wooden skewers, and sheets of Styrofoam, cellophane paper, and EVA, as depicted in Figure 2.

**Figure 2. Materials made available to students.**

Before the presentations on the last day of class, they signed the ICF (Informed Consent Form) and authorization terms for publishing images of their works. During the **presentation**, the students explained the activity's outcomes to classmates, covered the initial goal and discoveries, and provided a rationale for selecting data and materials. After the presentation, they were invited to complete a questionnaire to give **feedback** about the conducted activity, and they also had the opportunity to select the best work to be awarded a gift. Their responses are analyzed in Section 4.

### 3.4. Participants

The data physicalization activity applied in the second semester of 2023 was conducted in a class with 13 students, ten males, and three females, representing a distribution commonly observed in this Program. The majority of the students were either employed or

[3] http://tinyurl.com/3dmtt9m6
[4] http://tinyurl.com/25644xbh
[5] http://tinyurl.com/yh96zyh3
[6] http://dataphys.org/

engaged in internships. Three of them were graduating from the Computer Science Undergraduate Program and opted to enroll in the “Data Visualization” course to fulfill the remaining credit requirements.

## 4. Into the classroom: the experience

This section elaborates on the development of the activity, the works carried out, and the results achieved.

### 4.1. Creating the physicalizations

Among the 13 students, one participated in classes, helping his colleagues, but did almost all his work at home. Another only came in one development class and did a lot of research but did the work at home using Legos (material the teacher did not provide). The others did the work during classes, talking and exchanging ideas with their classmates and the teacher.

During the classes, the classroom setting was shifted to a different space, with larger tables and more spacious areas, fostering interaction. Figure 3 shows a part of this environment during the work development.

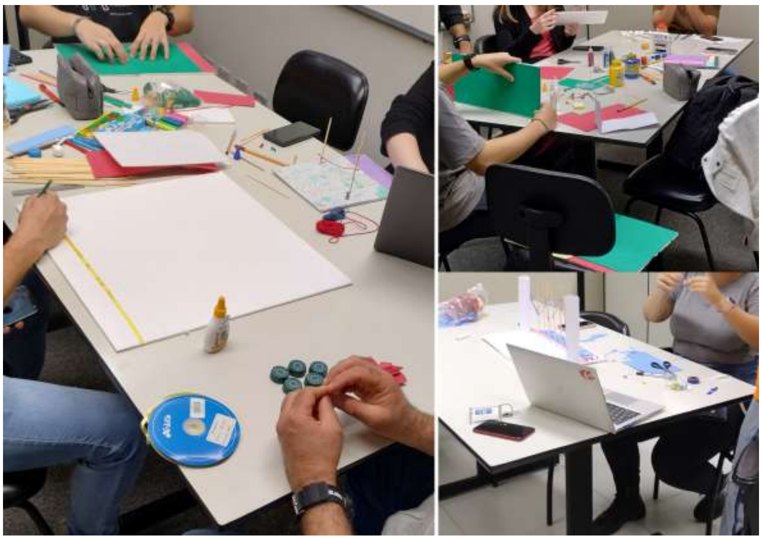

**Figure 3. Process of creating data physicalization.**

The resulting works were very diverse, as exemplified in Figure 4[7]: (a) variation in the Uber price depending on time and travel (home–work, home–university); (b) comparison of the total hours of sleep per day of two students considering assignments, exams, and parties; (c) the total number of commits on GitHub of the course completion work considering class days, exams and work submissions; (d) full hours of sleep per day at the end of the semester, when there are many exams and work submissions; (e) total number of draft beers consumed in few hours of intervals during an Oktoberfest[8]; (f) total glasses of water and cups of coffee drunk per shift during a week and its relationship with the total hours of sleep per day.

[7] We only list students who authorized their names to be associated with the developed work.

[8] An annual beer festival of German origin - https://www.collinsdictionary.com/dictionary/german-english/oktoberfest.

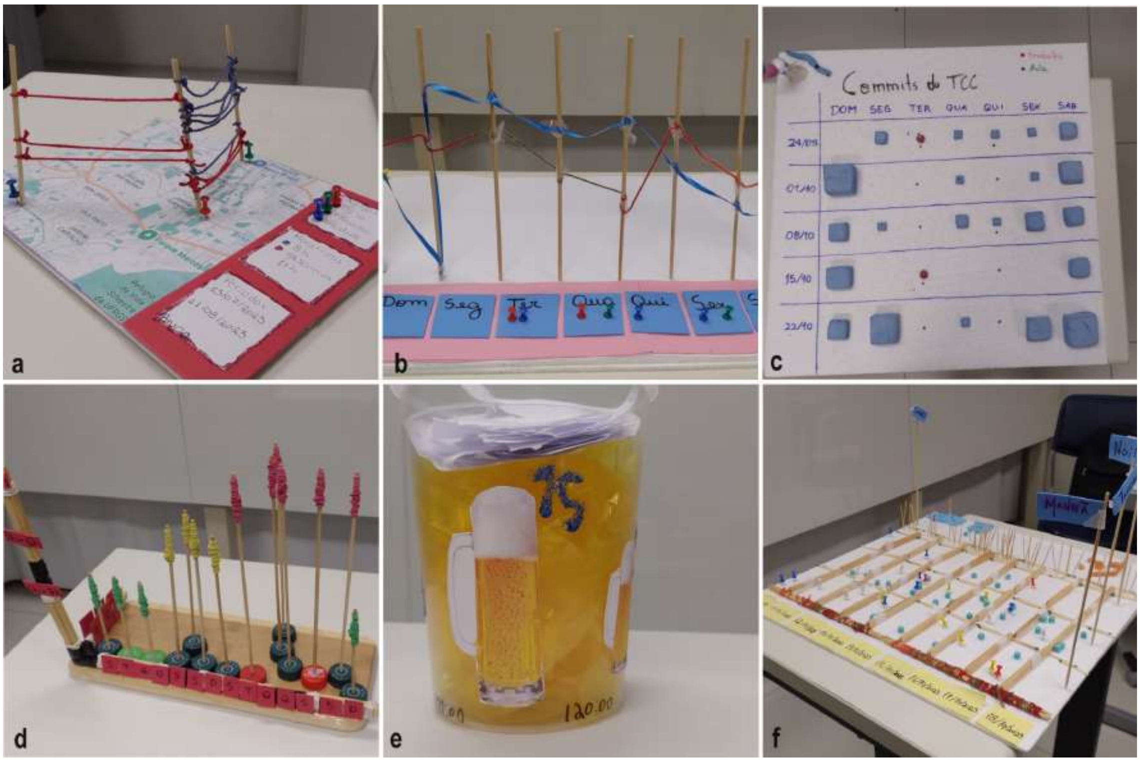


**Figure 4. Examples of the developed works. The authors of these works were: (b) Diogo da Conceição Vieira e Rafaela Varão Albuquerque, (c) Eduardo Cardoso de Andrade e Marcelo Peña Rodrigues Heredia, (d) Euzébio Henzel Antunes, and (e) João Vitor Abitante.**

### 4.2. Students' impressions

After the activity development and presentation, students are invited to fill out a form, recording their impressions about the activity. Eleven of the thirteen students participated in this phase, despite everyone signing the ICF.

Table 1 shows that most of the respondents enjoyed their participation in the activity (10 of 11), seeing gains in their learning process (9 of 11), and mainly, believing it supports them to exercise creativity and think about different ways to visual representation (9 of 11), and to understand the presented data (9 of 11). Only one student did not like the activity at all.

To help us understand the answers to the open questions that asked for more details about the choices presented in Table 1, we employed a textual analysis used in the open codification phase from the Grounded Theory [Corbin and Straus 2008]. Through this analysis, we found the highlight to the associated stimulation of **creativity** and creative thinking, to the **interaction and exploration** possibilities using the physical materials, and to the **engagement** that the activity promoted, considering its aspects of fun and routine break.

Seven of the 11 respondents point out the stimulation of **creativity** and creative thinking ("*a creative and different way to encourage creative thinking*" - P2[9] ). For instance, P9 said "*I think it helped to exercise creativity and think about different forms of*

[9]Each participant is identified as the letter P followed by a sequential number from 1 to 11

**Table 1. Number of students choices for each option (SA-Strongly agree; A-Agree; N-Neither agree nor disagree; D-Disagree; SD-Strongly disagree).**

| Impressions (Likert Scale) | SA | A | NAD | D | SD |
|---|---|---|---|---|---|
| Like to develop the activity | 6 | 4 | 0 | 0 | 1 |
| Believe the activity helped him/her in the learning process | 3 | 6 | 1 | 0 | 1 |
| Believe the activity helped him/her to exercise creativity and to think about different ways to visual representation | 8 | 1 | 1 | 1 | 0 |
| Believe the activity helped him/her to understand the data presented | 8 | 1 | 1 | 1 | 0 |

*visual representation because you have to think about different ways to represent data that are related to the person.*" and P11 highlights the "*This dynamic of making physical graphics encourages us to come up with ideas to create other ways of answering questions.*". P4 also underlines that "*Stimulating creativity in data visualization is essential.*". We believe the creativity inherent to the activity goal was the reason one student did not like the activity ("*I'm not a creative person, my chart was a standard scatterplot. If I were to explore something very different, it would probably be very difficult to explain or do.*". The (self-depreciative) consideration of his creativity skills could impact him in the whole activity experience.

Six of 11 respondents bring out aspects of **interaction and exploration** possibilities, mainly related to the tactile experience. P4 highlights that "*Exploring information tactilely can be a very useful tool for improving understanding, especially for people who learn best through tactile and sensory experience.*"; this is also emphasized by P10 ("*Because you are physically seeing, you can touch, rotate, feel, … for me it is better than a 3D simulation (...) in my view, people learn much more when using other types of stimuli, tactile, smell, hearing, etc. than relying solely on imagination to come up with a better idea*"). P7 calls attention to another fact that should be considered: "*Just as we can explore tactilely, in a computer visualization we can make other valuable interactions with the graph, such as filters, for example*".

Five of the 11 respondents described aspects related to the **engagement** that the activity promoted, considering its aspects of fun and routine breaks. P5 emphasizes that it was "*quite fun, stimulating the desire to participate*" and P7 that highlight found it "*fun overall, it also breaks the routine a bit*". The **routine break** is often associated with the funny aspect of the activity and for it to be a different way to participate in a class.

## 5. AFTER THE CLASSROOM: LESSONS LEARNED

Based on our experiences with the application of the data physicalization activity, we identified eight steps and other insights we believe could help other teachers interested in applying a different active methodology in a Data Visualization course. The steps are intentionally presented in a straightforward format depicted in Figure 5 and will be followed described.

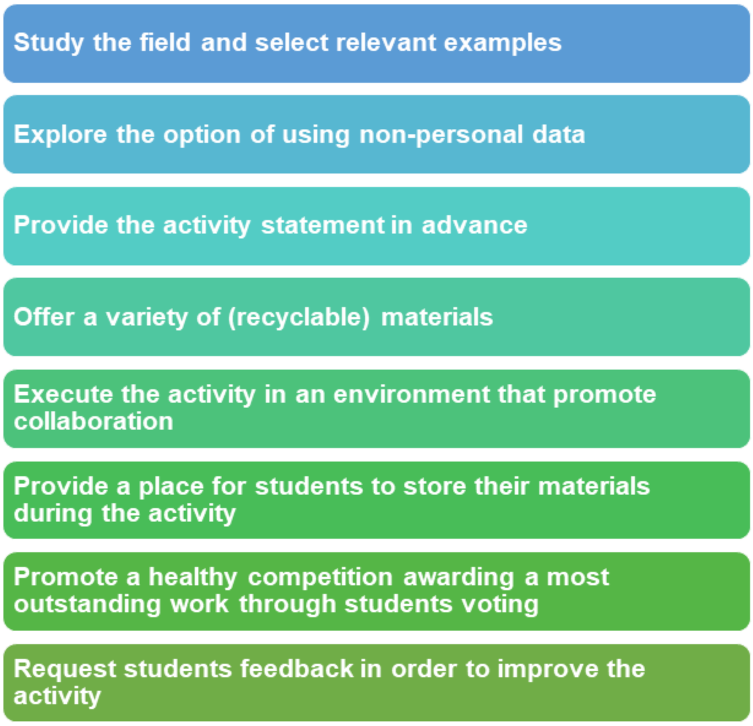


**Figure 5. Lessons learned of creating data physicalization.**

First, it is important that the **teacher has knowledge of the area and explores different examples**. This will help both in selecting materials for students and facilitating discussions about what each one will do. Students exchange many ideas about what they want to represent and how (or what materials) they can represent. These exchanges of ideas take place with the teacher and colleagues, promoting greater interaction in the class.

Following Perin's idea [Perin 2021], we work with the visualization of personal data. Most students enjoyed getting some insights from this. For example, a student whose work is depicted in Figure 4a was surprised by how much she spent on Uber. However, some students prefer not to use personal data, as appeared in the questionnaire feedback (one participant said: "'What I didn't like very much, but didn't impede the development of the activity, was the use of personal data." - P6). Maybe some people don't like exposing their data, and, for them, it would be interesting to have the **possibility of working with other data sets**.

It is important to **provide the exercise statement in advance**. Students need time to think about what they will do, collect data, and also think about the materials that will be necessary. In the case of temporal data, as many collected the information "by hand" (which was also reported in Perin's work [Perin 2021]), they need time to gather it. For example, in the work illustrated in Figure 4f, the student counted the amount of water and coffee he drank over more than a week.

The choice of **materials to be made available** influences the result of the work. Some students also bring material from home, but, for example, the student who developed the work in Figure 4e decided what to do when the plastic pot was provided to him.

This plastic pot was a package containing sweets, meaning using recycled material should be encouraged. In this sense, at the end of the presentation of the works, those students who would not keep the work and whose material could be reused were invited to return it. The student who did the work depicted in Figure 4d explained during the presentation that he also had this concern, as all the employed material could be reused.

Using a **different environment than the classroom**, with larger tables, greatly facilitated interaction between colleagues and between colleagues and the teacher. Furthermore, as it took two classes to complete the work, they could leave it in the room to continue in the next class. As the work is bulky and cannot be stored in a backpack, it is quite complicated to take it home and bring it back. Therefore, even if the work is done in the classroom, it is essential to **provide storage space**.

Many students are very motivated by the possibility of **being awarded for the best work**. It's important, however, that the voting process is conducted positively. Therefore, the chosen prize was a box of chocolate candies instead of a grade. In our second experience with this activity, which involved a smaller group, the student who won shared the chocolates with the whole class.

Finally, it is important to always **collect feedback from students**. Even if some students prefer traditional theoretical and practical classes, feedback helps to gain insights to improve the activity for new course editions. Furthermore, perception may vary depending on the profile of students in each undergraduate program or even country.

## 6. Final Considerations

Through different teaching activities, Computing education should instill several dispositions [Task Force 2020]. Considering these dispositions, the activity was Purpose-driven per se, as the students had specific instructions to follow. On the other hand, the nature of the activity could inspire the Inventive side of the students: students must look beyond the ways they are used to to envision novel forms to represent data. We observed the students being Adaptable and Meticulous, considering the final product they wanted to build. For those working in pairs or groups, the Collaborative disposition arises. Also, in some cases, it was notorious how Proactive and Passionate some students were when creating and talking about their projects.

As the following steps, we intend to continue improving the activity, taking into account the feedback received. For instance, we will explore using data, such as local city information, that could be easily gathered. We also intend to design new teaching activities to instill others of the desired dispositions [Task Force 2020].

We hope that the activity can inspire other teachers as Perin [Perin 2021] inspired us and that they also share their results. Thus, it is possible to create a knowledge-sharing that can assist in discussions on the computing education community related to this area.

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