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Let's Get Physical: From Data Visualization to Data Physicalization

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Work in progress

Let's get physical: from data visualization to data physicalization

Abstract

Data visualization is the practice of turning data into graphics and the usual goal is to communicate an interpretation of a dataset to a specific audience, to make an argument you have worked out from an analysis of the data or a sub-set of the data. It is an essential part of science and engineering communication [6,7]. A course that has been taught for the past 5 years in the Schulich School of Engineering at the University of Calgary added one more step in the data visualization process: data physicalization.

Art and engineering is a course that focuses on history, concepts, contemporary issues, and techniques of engineering in art. Topics include Arithmetic and Geometry, Proportion, Formalism, Symmetry, Computation, Geometric Abstraction, and Mathematics as they relate to engineering and art. Woven into the theoretical content are hands-on projects where students learn basic sketching skills, hand build a ceramic still-life piece, visit local galleries and museums, and, using elements or art and principles of design, turn data into data visualizations and data physicalizations: data-driven physical artefacts whose geometry or material properties encode data. Students use an adapted Jansen and Dragicevic [1] information visualization pipeline to move from raw data to data wrangling to visual and physical presentation. This paper presents examples of the process and concludes with observations and lessons learned.

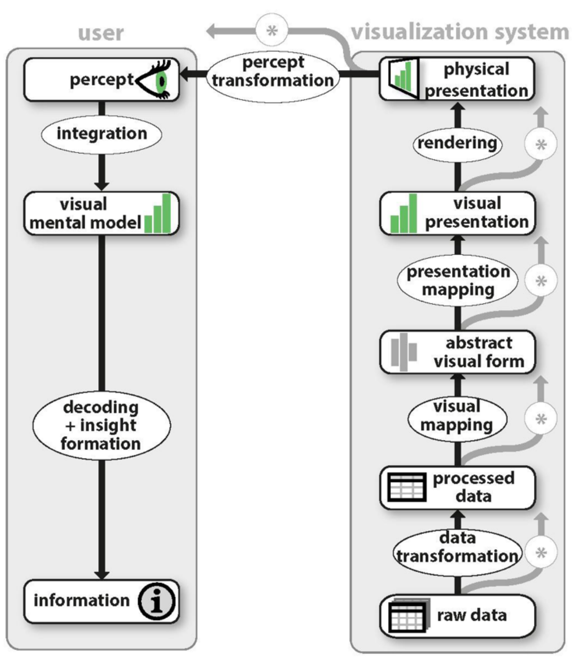


Figure 1. Information visualization pipeline. Jansen and Dragicevic (under CC-BY-SA license) [1].

1. Introduction and history

What is data physicalization?

A data physicalization (or simply physicalization) according to the paper *Opportunities and Challenges for Data Physicalization* "is a physical artifact whose geometry or material properties encode data" and "a research area that examines how computer-supported, physical representations of data (i.e., physicalizations), can support cognition, communication, learning, problem solving, and decision making [2]."

We can also think of these as analog data storage devices. A historical example is the Quipus – a complex collection of knotted ropes that played an important role in Inca administration. The variation in the knots is thoughts to encode quantitative variables and indicate various categories. A wealth of examples can be found on the physicalization gallery on the website dataphys.org.

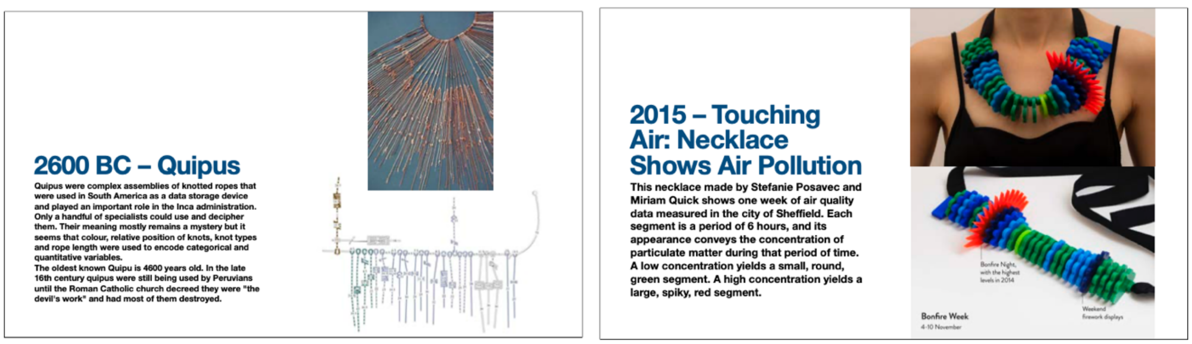


Figure 2. Sample slides showing a historical example: 'Quipus' and a contemporary data physicalization from 2015.

My own experience with data physicalization was from a series I did based on our city's homeless count. The city does a Point-in-Time Count: a survey that counts the number of people experiencing homelessness on a particular night. The survey, which takes place every two years, highlights how homelessness is changing and helps the city decide how to allocate resources and create a system of care that best serves this vulnerable population. From 2000 to 2008, I represented *Street Data* gathered through an in-person survey of people sleeping in places like vehicles, tents and makeshift shelters using multiples: small objects like monopoly houses (Figure 3). The point was to make a number visual and physical, but the data was not analyzed beyond this and no meaning was assigned to the colour of the Monopoly houses.

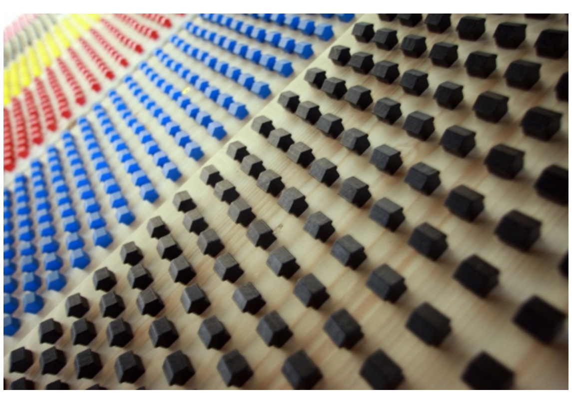


Figure 3. Data physicalization of 2008 homeless count (4060 monopoly houses) by the author.

To start the student data physicalization project I used a data visualization approach – *Dear Data* - successful in past years in our first-year engineering design class so that students could see their data start to take shape (see appendix 3 for a complete *Dear Data* assignment).

Dear Data (http://www.dear-data.com/by-week/) is an analog data-drawing project. Each week the two designers who started this project would collect the same data about their lives. Examples include 'urban animals' (which animals did they observe in their city during the course of a week) and a week of sound (which sounds did they hear over the course of a week at regular intervals). The data was then analyzed and turned into a hand-drawn visualization and sent via 'slow data' transmission (by mail) to in this case another continent. The front of the postcard showed the visualization, the back had a legend so you could 'read' the front. The designers classify their project as a 'personal documentary' rather than a quantified-self project which is generally about becoming efficient and to gain 'useful' self-knowledge.

Dear Data is very inspirational and the perfect method to have students work on their own small personal data sets, particularly because it allowed for 'experimentation without fear' – the assignment (Appendix 1) allowed for lots of experimentation and there was no 'rights answer'. Students could choose from the data collection themes of *Dear Data* to see what would happen with the same prompt or choose to collect data about themselves: study habits, time spent on their phone, app use, food habits, etc. More often than not the assignment resulted in a student changing their habits – in these cases it did become a quantified-self project.

The process students followed was an adapted pipeline (Figure 4) based on the information visualization diagram (Figure 1) by Jansen and Dragicevic [1]. From left to right and top to bottom students collected raw data for a week and were asked to add details about context – for example: Who was involved? What happened? Where did it take place? Why did it happen? How did it happen? They were asked to transform and create multiple views (to start seeing correlations and patterns) of the raw data to processed data using excel and a number of suggested links (an example: RAWGraphs). The third page of the pipeline encouraged inspiration from existing historical and contemporary data visualizations which they were shown in a 'History of data visualization' lecture. Then, moving from processed data to abstract visual form meant student started to make decisions about the data story they wanted to tell. The next step, visual presentation, was to make decisions on colour, shape, size, and pattern to start encoding the data. A postcard design and a legend were the final steps in the data visualization. A student example can be seen in appendix 3.

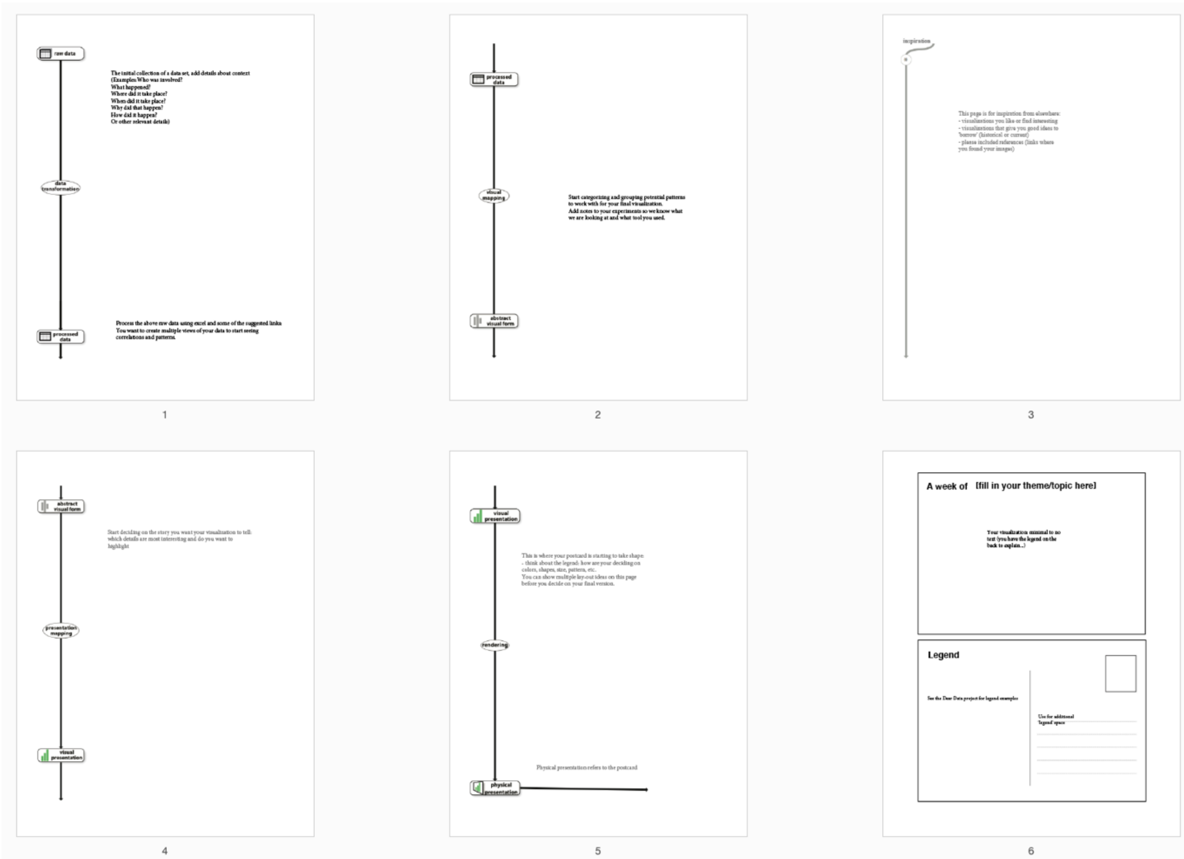


Figure 4. Student data visualization pipeline adapted from Jansen and Dragicevic (under CC-BY-SA license).

In the first-year class we added a small data physicalization project to give students an introduction to Autodesk Fusion360 and the university's maker-space. This 'Fusionvis' assignment (Appendix 2) meant students had to complete a 2-part training session to get access to the maker-space, and complete introductory 3D modelling tutorials. We included a size restriction so that all 900 students could print a personal data token [5]. A few examples can be seen in Figure 5: we asked students to create a simple object importing a 2-dimensional image and adding thickness - this worked in most cases.

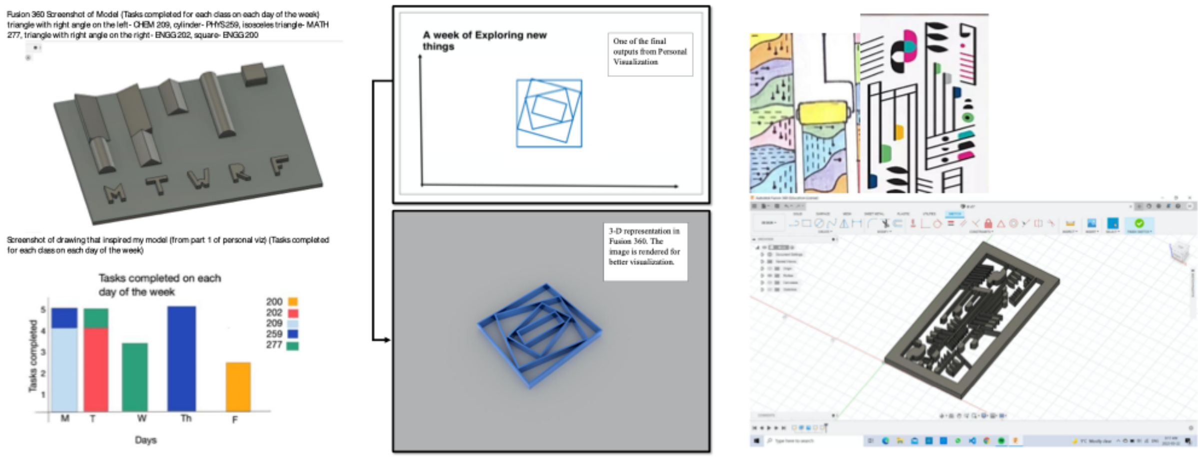


Figure 5. Examples of a simple data physicalization exercise to introduce engineering students to working with 3D modelling software.

2. Data physicalization in the current course

Art and Engineering is a course that focuses on history, concepts, contemporary issues, and techniques of art as it relates to engineering. Topics include Arithmetic and Geometry, Proportion, Formalism, Symmetry, Computation, Geometric Abstraction, and Mathematics connected to historical, theoretical, and critical contexts in art and engineering. Students gain experience and a working knowledge of concept development and the creation of engineering-inspired art projects. Students from all six engineering departments at our school can take the course as a complementary studies course. On average the class has 25 students.

We start the class with a discussion of the short article *What Art Unveils* by Alva Noë which usually allows us to find aspects we agree on so that we have a common understanding of art in the course. 'Artists make stuff' – we were able to agree on that. Noë's hypothesis is "that artists make stuff not because the stuff they make is special in itself, but because making stuff is special for us. Making activities — technology, for short — constitute us as a species. Artists make stuff because in doing so they reveal something deep and important about our nature, indeed, … about our biological nature [4]." He continues the article that 'art makes things strange': take a group of engineering students to a gallery (which I did) and you will have your answer – we agreed on this also. Noë writes: "Design, the work of technology, stops, and art begins, when we are unable to take the background of our familiar technologies and activities for granted… [d]esign, at least when it is optimal, is transparent in just this way; it disappears from view and gets absorbed in application [4]."

The class is structured around a framework of elements of art and principles of design. Students are introduced to these concepts over the course of 12 weeks with assignments to explore elements like line, shape, form, and space, and principles like balance, contrast, and pattern.

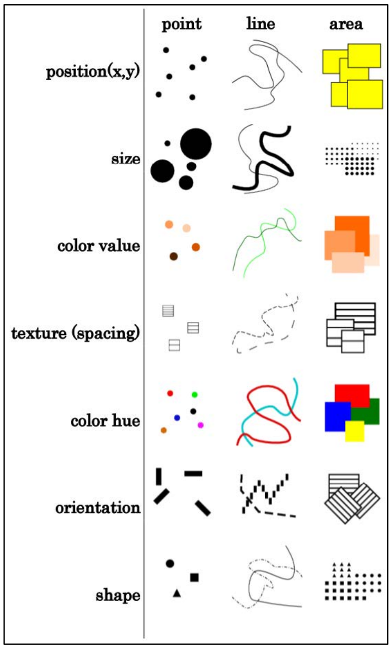


Figure 6. Bertin's Visual Variables

These elements and principles are very useful for data visualization and physicalization and are referenced in early texts for data mapping. For example, Jacques Bertin in *Semiology of Graphics* (1967) proposed a set of "visual variables": Position, Size, Shape, Value (lightness), Color hue, Orientation, and Texture (Figure 6). In the first-year design class we had also introduced students to Gestalt principles and visualization. These principles describe how humans group similar elements, recognize patterns and simplify complex images when we perceive objects, and our natural compulsion to find order in disorder [9].

The data assignment allowed students to use and apply elements and principles they had experimented with for the first half of the semester (Figures 8-10). The first half of the semester also included re-creations of famous works of art using minimal materials (Figures 7 and 11), and a stop-motion video project. The final projects are chosen by the students from four themes: composition, environment, medium, or material [11].

Figure 7. A student's contemporary interpretation of Vermeer's Woman Holding a Balance *(courtesy of Noam Anglo).*

For the data physicalization assignment, one student was inspired by the Quipus and data scarfs and blankets, where the colours of the various knitted sections represented temperature ranges or bus stop wait times, that were shown in the history of data physicalization lecture. She also added friendship bracelets as an inspiration for her final deliverable. It was interesting to see the translation from data generated by excel and other tools into the bracelet and how the information was codified. The data is very personal and she indicated that she had an immediate emotional connection to the object she had created (Figure 9).

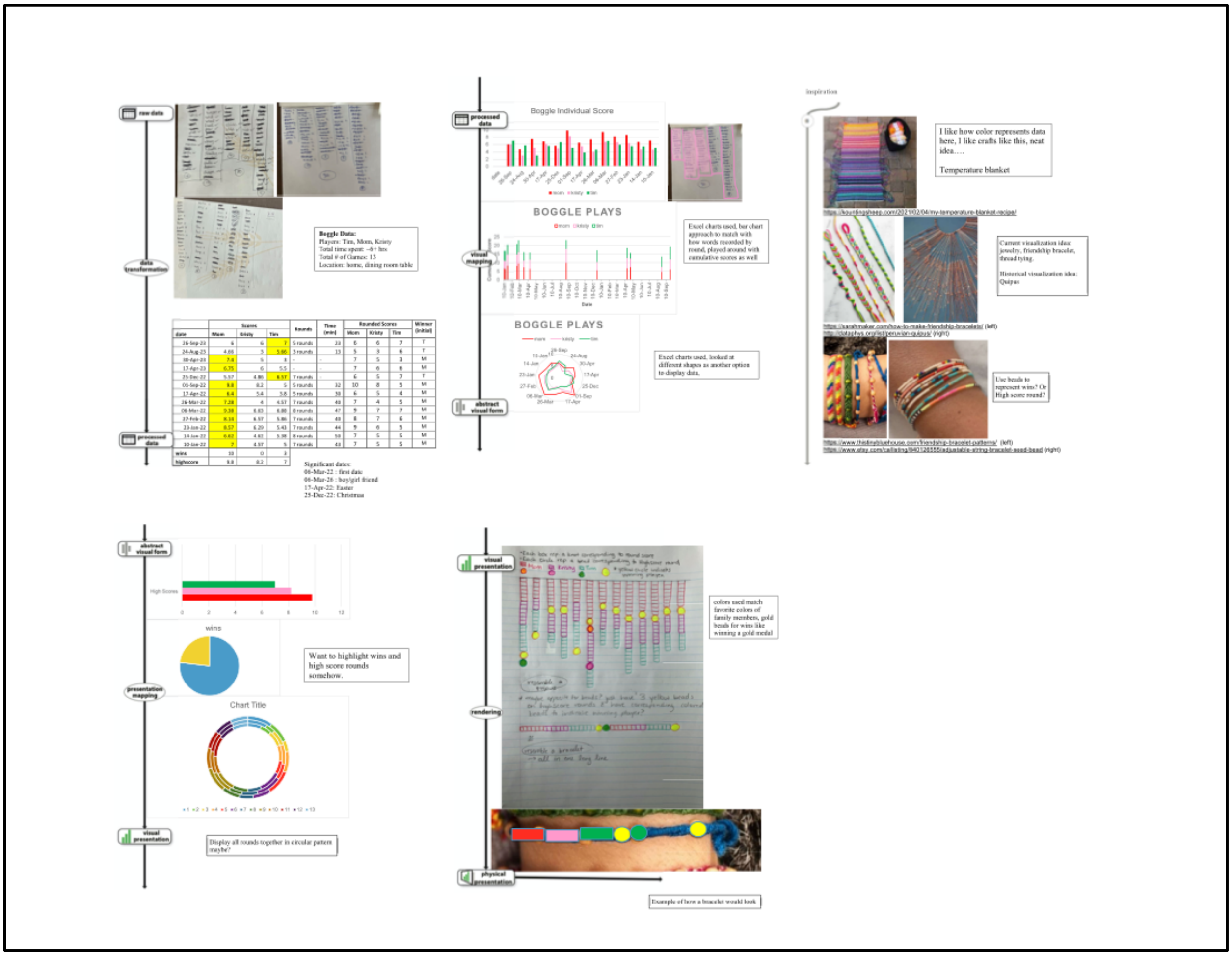


Figure 8. Student data visualization pipeline in preparation for data physicalization (courtesy of Kristy Olmstead)

Figure 9. Student data physicalization bracelet inspired by the Quipus (courtesy of Kristy Olmstead)

Another example from this project was the comparison between the increase in housing prices and the relative sad state of average incomes. The student is being generous with the representation because the incomes are around $36,000 and the lowest housing price is $243,000. The income data pieces would actually disappear inside the tray but he wanted the pieces to be easy to handle (and easy to 3D print). In this case he followed the data visualization rule that data should be easy to understand at a glance but not that the data also has to be truthful and precise. We discussed this in the group and a number of students expressed that it was quite difficult to assign data characteristics accurately and that they had taken artistic license in some cases which for the course was paramount, for engineering courses less so.

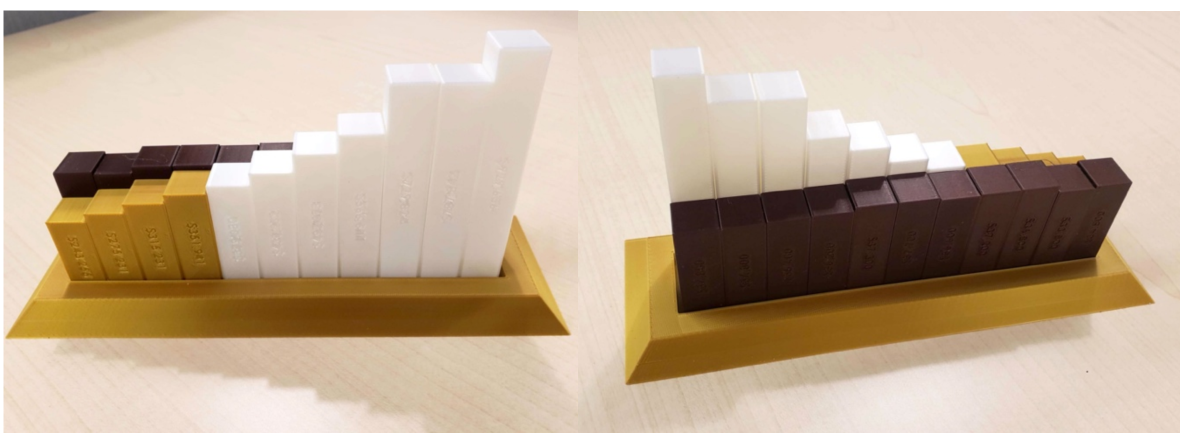


Figure 10. Student data physicalization showing increase in housing prices (white/gold) vs income (brown) (courtesy of Christopher Vo).

3.0 Discussion and student feedback

A number of benefits related to data physicalization have been identified. Jansen et al. note that it takes advantage of our active perception skills by allowing someone to rotate a data object or walk around a larger data physicalization. Physical objects can also give us cues of shape and volume thereby leveraging our spatial perception skills. And while vision is the dominant way in which most of us perceive the world, data physicalization opens up additional sensory avenues like sound, touch and smell to name a few. Physicalizations are also thought to benefit cognition and learning. Physical representations were historically used to teach concepts in mathematics, chemistry, and biology. More recently, in his famous TED talks, Hans Rosling used physicalizations to explain global population growth and other world statistics collected via Gapminder engaging large audiences with data [10]. In addition, educational psychology has found evidence that supports the "embodied cognition thesis, according to which cognition is supported by the body and the physical world [2]."

One student shared the following:

> "I really enjoyed the data physicalization project, I definitely felt that seeing or being able to touch the data made it much more impactful. Some of the videos we watched, or your data sets with people represented by little [houses] really put numbers that we brush by as inconsequential in perspective. I definitely thought it was a cool project, and a good one for engineers, we work with so much data that's visualized through graphs but that doesn't mean we understand it all the time or comprehend the magnitude of numbers.
>
> My project on *Boggle* [a word search game] data was just a fun data set to use, something from everyday activity, but really put into perspective how many wins my opponents (mom and brother) have! I thought it was cool to learn about the Quipus and see such an old example of data physicalization. Overall that project is probably a reason I would recommend the course to other engineering students, it was very valuable."

To conclude this anecdotal narrative, data physicalization in this course and in a past first-year design course indicates that this exercise is useful for students. It allows data to become personal and tangible, allows for greater meaning and impact of a data set, allows for transdisciplinary collaboration, and allows for communication with non-experts. As a next step I plan to implement data physicalization in a bio-inspired design course where comparative data between various species could be meaningful to visualize as physical objects as it relates to design abstraction and creating a connection to other species. Our classes are moving further and further from physical reality and have become digital and virtual. If we agree that making stuff is special for us, data physicalization could be an avenue to get back to making, to increasing sensory avenues, to including other ways of knowing, to spatial perception, to embodied cognition. A paper from 2013 discussed design for emotional attachment and technological adaptability as an approach to combat planned obsolescence in product design, diminished user experience, and shorter product lifespan [12]. Data physicalization could be an approach to bringing an emotional connection to a data set especially when it is data collected about ourselves or about the worsening state of our planet. Data and engineering are not neutral and there is anecdotally potential for physical data objects to bridge to a deeper and more meaningful understanding.

Figure 11. A student's contemporary interpretation of Dali's The Persistence of Memory *(courtesy of Kelly Long).*

And to finish with Noë it allows students a way of investigating the world and themselves: "art displays us to ourselves, and in a way makes us anew, by disrupting our habitual activities of doing and making [4]." I hope this work in progress inspires others to experiment in their classes and that multi-year studies will follow in future years.

The author would like to thank Kristy Olmstead, Noam Anglo, Christopher Vo, Kelly Long and Maham Jamal for their great work and contributions.

References

[1] Yvonne Jansen, Pierre Dragicevic. An Interaction Model for Visualizations Beyond the Desktop. *IEEE Transactions on Visualization and Computer Graphics*, Institute of Electrical and Electronics Engineers, 2013, 19 (12), pp. 2396 - 2405.

[2] Jansen, Y. Dragicevic, P. Isenberg, P. Alexander, J. Karnik, A. Kildal, J. Subramanian, S. and Hornbæk, K. Opportunities and Challenges for Data Physicalization. *CHI 2015*, April 18–23, 2015, Seoul, Republic of Korea.

[3] Data Physicalization Gallery, http://dataphys.org/list/gallery/

[4] Noë, Alva. "What Art Unveils." *The New York Times*, The New York Times, 5 Oct. 2015, archive.nytimes.com/opinionator.blogs.nytimes.com/2015/10/05/what-art-unveils/.

[5] Rohit Ashok Khot, Larissa Hjorth, and Florian 'Floyd' Mueller. Understanding Physical Activity through 3D Printed Material Artifacts. *CHI 2014*, April 26 - May 01, 2014, Toronto, ON, Canada.

[6] Vetria L. Byrd. Usability of Data Visualization Activity Worksheets in the Context of a Critical Data Visualization Workshop: Findings from a Usability Survey. *ASEE 2020*, July 22-26, Virtual Conference.

[7] Vetria L. Byrd. Innovative Pedagogy for Teaching and Learning Data Visualization. *ASEE 2021*, July 26-29, Virtual Conference.

[8] Bertin and Berg, *Semiology of Graphics: Diagrams, Networks, Maps*. ESRI Press, 2011.

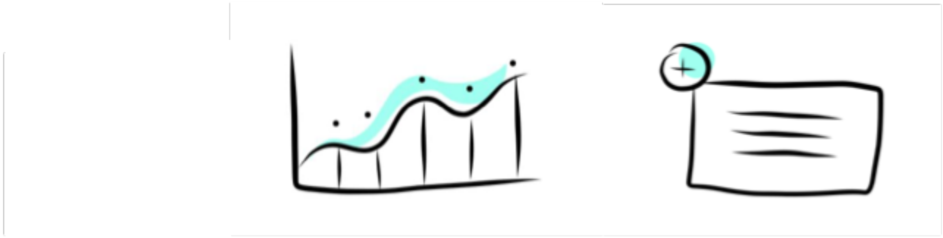
[9] Gestalt psychology, https://en.wikipedia.org/wiki/Gestalt_psychology

[10] Hans Rosling, https://www.ted.com/speakers/hans_rosling

[11] McFarland, Joe. "When Art and Engineering Collide." UToday News, 11 Jan. 2022, ucalgary.ca/news/when-art-and-engineering-collide

[12] Lobos, A. Babbott, C. Integrating Emotional Attachment and Sustainability in Electronic Product Design. *Challenges* 2013, *4*, 19-33; doi:10.3390/challe4010019

Appendix 1. *Dear Data* personal visualization assignment



Engg 200 Personal visualization project

Due on D2L (PVs dropbox folder) Feb. 6 at 11:59 pm: One completed process PDF
Please use one of the process templates (pages, word, pdf) posted on D2L (or recreate)
[See pdf for correct spacing and annotations - make sure you delete the annotations if using the PDF template]

Steps:

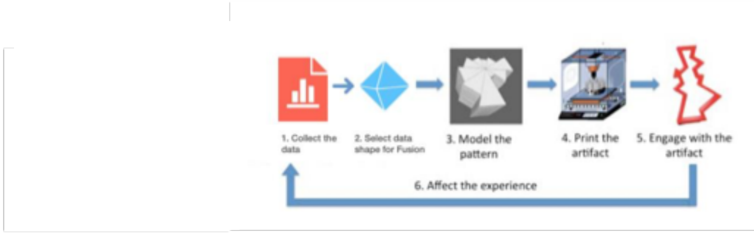
- Week 1: Pick or modify a topic/theme from this page: http://www.dear-data.com/by-week/ and collect data for one week. Pick something that is useful for yourself or something you are into already: exercise, food, study habits, patterns in your life, mood, getting to class, etc.
    - Please note: when collecting your data write down the 'context'. For example: where you were, time of day, people around you, sounds, colours, details linked to your data, etc. Contextual data will show you patterns more easily.
- Week 2/3: Process the data using the steps in the template (see AGoodProcessToFollow.pdf for the right questions to ask, think about context, and about the 'story' you want your final visualization to tell). Create a visualization postcard - this can be analog (hand-drawn and photographed) or digital.

Some online resources that are useful (to process the raw data):

Tableau Public: https://public.tableau.com/en-us/s/
RawGraphs: http://app.rawgraphs.io
[**Please note:** the graphics generated via the tools above should not be submitted as final visualizations – use them and tweak them to create your own unique summary]

For visualization examples:

http://www.informationisbeautiful.net/
https://datavizcatalogue.com



Engg200 Fusionvis: Personal data physicalization* project

Due on D2L (Fusionvis dropbox folder) March 20 at 11:59 pm:

- One STL file (from Fusion360)
- a Fusion360 screenshot of your file + the image/file from your personal data that was the starting point for your Fusion sketch saved as a 1-page PDF.

Due on D2L (Fusionvis dropbox folder) last day of classes:

- A selfie with your 3D printed datavis to the same dropbox.

First: Make sure you have finished Maker Multiplex & Zetta: General Access Training

https://schulich.libguides.com/m2z/general-access-training

and 3D Printing: Basics

https://schulich.libguides.com/c.php?g=726179

Next steps:

- Watch the Fusionvis video and have a look at the dataphys links below
- From your personal visualization project find a suitable visual to use for this project (it does not have to be your final visualization image – can be from the visual mapping phase for example)
- Create your STL file in Fusion360, making sure constraints (below) are satisfied
- Upload to the makerspace 3D printers **using the following naming convention**: Course name and number (all capitals), followed by a dash, your UCID, another dash and the description of the part (example: ENGG200-10045678-Part1)
- Constraints:
    - Size envelope (**maximum** dimensions): 4 cm by 8 cm by 3 mm (thickness)

Fusion 360 link: https://www.autodesk.com/education/students

For data physicalization* examples and ideas for your data and 3D print:

http://dataphys.org/list/data-jewelry/

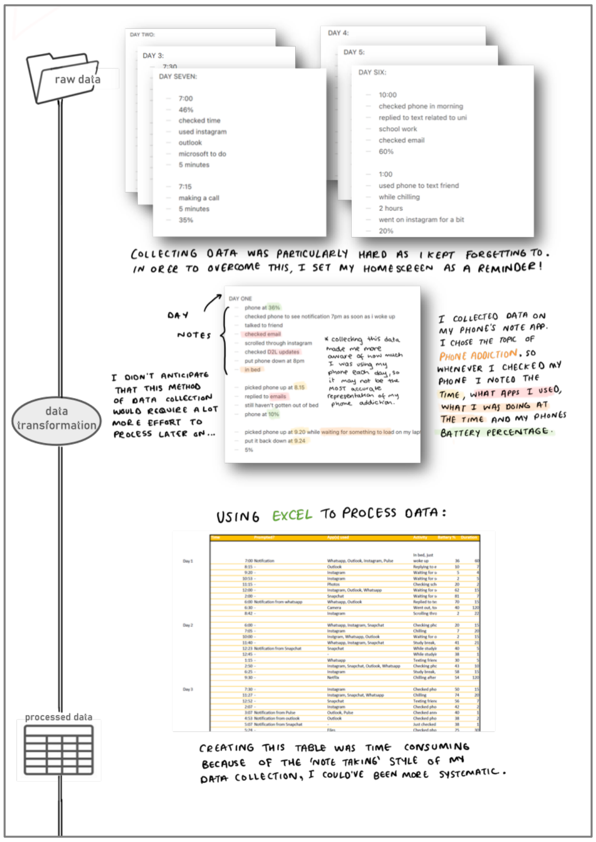
http://dataphys.org/list/wearable-self/

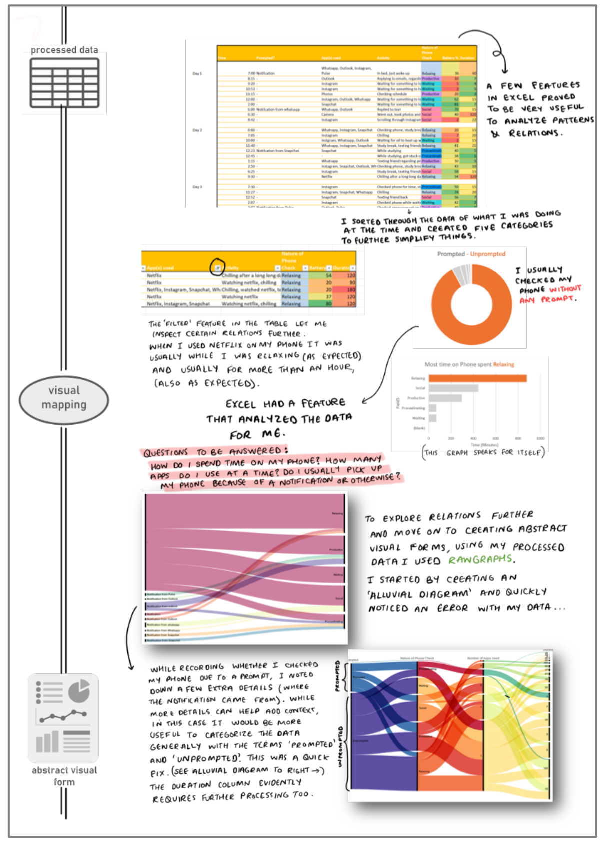
http://dataphys.org/list/data-necklace-of-good-night-sms/

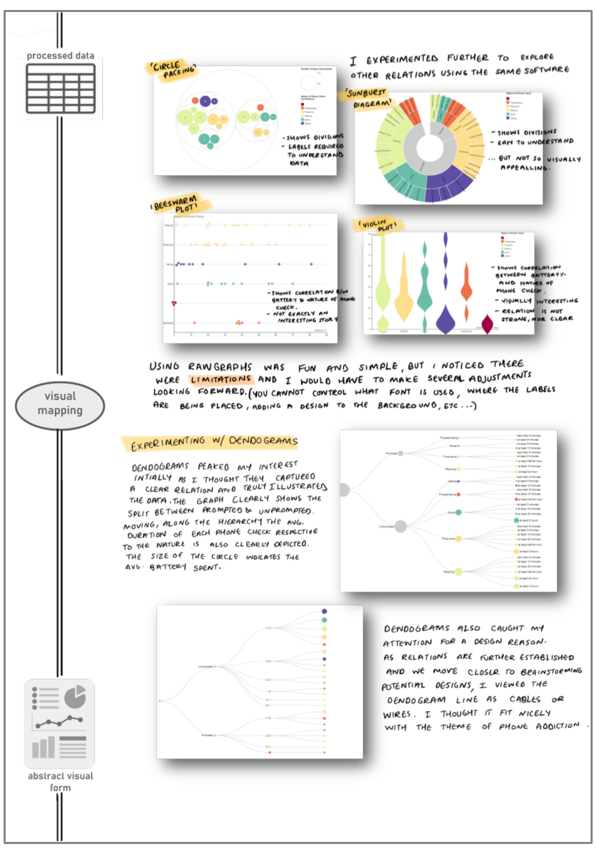
*Data physicalization: representing data in physical form.
Image credit: https://exertiongameslab.org/wp-content/uploads/2011/07/understanding_3d_chi2014.pdf

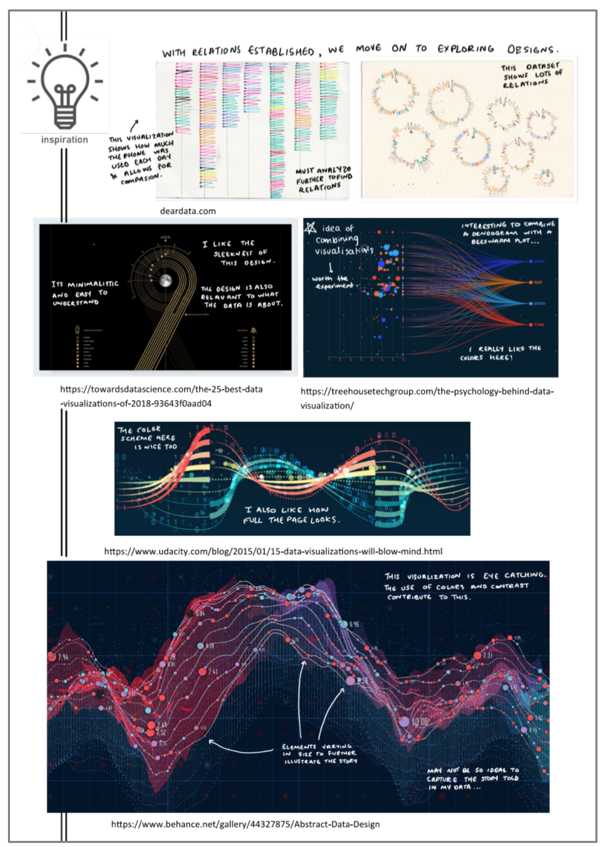
Appendix 2. Fusionvis data physicalization with Autodesk Fusion360.

Appendix 3. *Dear Data* student data visualization (courtesy of Maham Jamal)

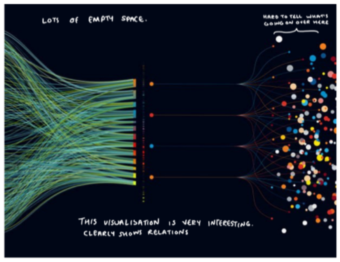




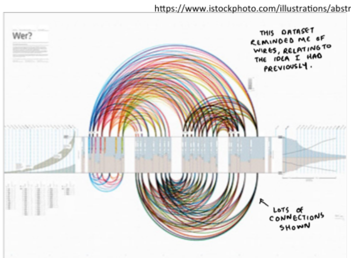




inspiration



https://www.istockphoto.com/illustrations/abstract-data-visualization



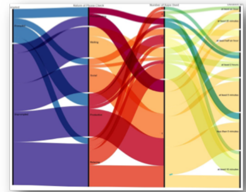
http://www.visualcomplexity.com/vc/project_details.cfm?id=454&index=454&domain=

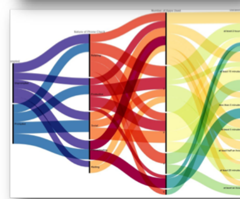
AFTER LOOKING FOR INSPIRATION I NARROWED DOWN WHAT I WAS PICTURING MY DESIGN TO LOOK LIKE:

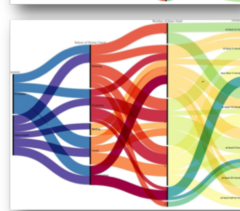
- A DARK SCHEME COLOR
- LOTS OF ELEMENTS SHOWING DIFFERENT ELEMENTS OF THE DATA
- POSSIBLY COMBINING TWO DIFFERENT WAYS TO VISUALIZE.
- SHOW RELATIONS DISTINCTLY AND CLEARLY.

abstract visual form

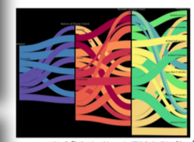
presentation mapping



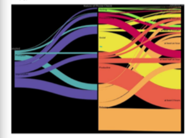




I REALLY LIKED THE WAY THE ALLUVIAL CHARTS SHOWED CONNECTIONS SO I EXPERIMENTED FURTHER WITH THAT.



THE WIDTH IS PROPORTIONAL TO BATTERY CONSUMPTION



ONLY ONE STEP IS NOT VERY INTERESTING

I LIKED THE WAY THE TRANSLUCENT STREAMS LOOKED.

THE DARK BACKGROUND AND OPAQUE STREAMS GAVE A MORE SLEEK AND FINISHED LOOK.

UNFORTUNATELY, THE TRANSLUCENT STREAMS DID NOT SHOW UP WITH A DARKER BACKGROUND.

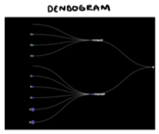
visual presentation

GENERALLY, I WAS HAPPY WITH THE PATTERNS THESE GRAPHS WERE SHOWING ALONSIDE BEING VISUALLY APPEALLING. HOWEVER, IT STILL FELT AS IF SOMETHING WAS MISSING...

visual presentation

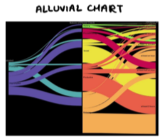
...SO I EXPERIMENTED WITH COMBINIG TWO GRAPHS.

DENDOGRAM



+

ALLUVIAL CHART



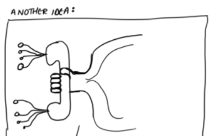
combining charts:

I COMBINED THE ABOVE CHARTS BY DRAWING OVER THEM AFTER PLACING THEM TOGETHER.

rendering

IN THIS VISUALISATION I COMBINED A LINEAR DENDOGRAM WITH AN ALLUVIAL CHART. I ADJUSTED THE SOURCE NODE OF THE DENDOGRAM TO LOOK MORE LIKE A PHONE TO FIT IN WITH THE THEME.

ANOTHER IDEA:



- ☑ VISUALLY INTERESTING
- ☑ RELATES TO THEME
- ☑ TIME CONSUMING
- ☑ WORTH THE TIME?

THE NODE FOR PROMPTED/UNPROMPTED CAN MOLD INTO A HAND WHICH IS GRABBING THE TELEPHONE.

* DIMENSIONS HERE ARE ELONGATED. IN THE FINAL PIECE, IT SHOULD AGREE W/ THE DIMENSIONS OF A STANDARD POST-CARD. (THIS IS A DESIGN CONSTRAINT)

HOW DO I SPEND TIME ON MY PHONE? HOW MANY APPS DO I USE AT A TIME? DO I USUALLY PICK UP MY PHONE BECAUSE OF A NOTIFICATION OR OTHERWISE? } ALL QUESTIONS ARE ANSWERED! :)

physical presentation

I WAS HAPPY WITH THE FLOW OF IDEAS AND SO DECIDED TO WORK ON THE FINAL VISUALISATION.

Final Visualization