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| How People learn project |
| A study on the benefits of interactive visualization on learning experience of students |
| The purpose of this project is to study how interactive visualizations help students understand scientific phenomenon much better than mere equations and how this better understanding translated to a more engaging and fruitful learning experience to them. |

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**Executive Summary**

The objective of this project is to evaluate the effects of multiple types of learning media on the learning experience of the students. For the purpose of this project, we used the equations of force and momentum {eqn here} and recorded the textual feedback of students after being exposed to the concepts in the following order:

1. Exposure to text describing the equations and the phenomenon.
2. Exposure to text and static plots which further shed light on the concepts.
3. Exposure to interactive visualizations we developed to further engage the students and provide additional insights.

The analysis of the feedback from the students showed that Interactive visualization enable students to have additional insights into the concepts which, are somewhat obscure in textual descriptions and static plots. Especially apparent through interactive visualizations was how the curves will vary their shape when certain parameters are changed and how much dependency each formula has on a certain parameter.

The results of this study corroborates with the expectation established in cognitive theory that feedback and variegated modes of instruction transmission ( textual and graphic ) help the students with variegated learning and perceptual styles learn better {quote here } . Even more so, the interaction capability afforded by the interactive visualization helps the students engage more and have a deeper learning than a surface learning {quote here } .

Designing the interactive visualization for the client was done in Python, as the client has requested to translate pre – existing concepts in Mathematica to Python. Sympy package{quote} in the python ecosystem was used for symbolic equations, Scikit-learn was used to solve the symbolic equations which formed the basis of concepts we expected the students to learn in this project. Visualization was rendered on Jupyter {quote} notebooks by using a library Holoviews {quote}. The project’s design phase took around 40 hours to complete which involved technical implementation of concepts programmatically as well as implementation of the visualization framework.

**Introduction**

Visualization is a powerful tool for concept exploration and analysis. According to Prucha {ref } , visualization of information has universal clarity irrespctive of variery of languages , relativity etc. There’s a danger however which is not established by Prucha{ref }, which is hypertrophy of sensory impressions and quite frequently ambiguity of information. According to historical developments, the progress of mathematics has been linked with development of several semiotic systems from the primitive duality of cognitive modes derived from different sensory systems : language and image. Symbolic notations emerging from language have lead to writing which is primarily algebraic whereas for imagery, the construction of plane figures and graphs lead to emergence of curves. The new semiotic systems provided means to depict, process and learn mathematical thinking better. {ref : Duval 1995b} . Thus, we have several registers for discursive representation and several systems for visualization. That entails a complex cognitive interplay underlying any mathematical activity. What remains to be established is how well balanced is the sensory load towards language versus imagery which remains to be established.

Interactive visualization especially presents the users with an opportunity to decide on the “what” and the “how” of the information presentation. Let’s elaborate the two questions on which the remainder of study is built:

1. “What” : It refers to the qualitative understanding , i.e. surface learning represented by understanding the equations given below without having understood the parametric relationship existing within the system, i.e. without understanding how such a system interacts with its environment as well as how this system is affected by external stimulus.
2. “How” : It refers to the quantitative understanding , i.e. deep learning represented by focusing on key intricacies of the concepts presented to the students, they try to understand it better so that they can very will understand the effects of different stimulus on the system, and how different parameters affect the system represented by concepts.

As is apparent, interactive visualization does provide the audience with the means to delineate what from how but how effective or useful is this delineation remained to be established. To be more precise, in this study, it will be validated if and the enlarged scope of action on the side of the user leads to a better processing understanding of the presented information. From a cognitive standpoint, the cognitive costs of introducing interactivity have been extensively discussed within the framework of cognitive load {e.g. Conklin, 1987 Conklin, J. (1987). Hypertext: An introduction and survey. IEEE Computer Magazine, 20 (9), 17-41,} however, its possible cognitive benefits have not attracted a comparable attention. But according to { Kirsh, D. & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. Cognitive Science, 18, 513-549. } interactively modifying an external information presentation may serve a number of cognitive purposes. By use of such “epistemic actions”, mental processes may be facilitated and simplified, either by reducing the number of elements that have to be held in memory, by reducing the number of mental processing steps, or by making the whole process more reliable { quote <https://www.iwm-tuebingen.de/workshops/visualization/schwan.pdf> }

In order to confirm the hypothesis, we have designed the study in following 3 phases :

1. Stage 1 : Expose students to equations and text explaining the concept as shown below {pic below} . After explanation, ask a set of questions to establish a baseline of learning effectiveness of this medium.
2. Stage 2 : Expose students to static plots and figures alongside the equations and text which should help them better understand the concepts. After exposure, we follow up with a set of questions to help understand of the effect of the medium on student’s learning ability.
3. Stage 3 : Expose students to the interactive visualization we have developed and we let the students interact with the intended interaction features of the visualization. The questions following this are aimed at ensuring that students can properly explore all the features that the visualization has to offer followed up by the questions which help us understand the effectiveness of the new medium. The design of interactive visualization and the questionnaire is explained more in detail in the appendix {which one ? } .

While developing the interactive visualization, we have to decide not just the content delivered to the students, but also what aspects of information will be amendable, which then affects what interactions would be useful to the students, and how useful would be the interaction to the students in the understanding. Thus, as designers we have to blur the boundary between us and the the users to be able to design the most effective visualizations. This effect was studied more by {quote here (Kirchmann, 1994). Umschalten erwünscht? Wen ja, von wem? In H. Schanze (Hrsg.), Medientheorie –

Medienpraxis. Arbeitshefte Bildschirmmedien 48 (S. 23-60). Siegen. } and also studied in a study called “Hypervideos” by { quote Zahn, Schwan & Barquero (in print). Authoring Hypervideos: Design for learning and learning by design. In R. Bromme & E. Stahl (eds.), Writing Hypertext and learning. Pergamon Press. } . They define hypervideos to be videos with hotspots which is like links in hypertexts and allows users to click to be directed to other media such as text , clip or illustrations. The conclusion of the study was that users weren’t distracted by the design decisions made by the designers, rather domain specific design decisions made by the designers who’re familiar with the topic made comprehension easier for the intended audience.

Elements of Visualization followed in the design :

* Good readability , appropriate fonts , not distracting fonts.
* Use of color – less is more , and maintaining the colloquial similarity in colors such as , - green positive, versus red negative {ref : (Drtina, Chrzová, Maněna 2006 in Bilek et al. 2007).}
* According to {ref: Happonen and Aksela (2011) } key problem subjects have is in reading the x and y axis, so we ensured that the axis fonts have good size which doesn’t eclipse readability.
* The composition of layout also follows the format established by . Seifert (2004) in Bilek et al (2007)

**Findings and Discussion**

Based on our survey results on 12 EPFL first year Material Science students, we can arrive at the following conclusions:

1. The amount of insight students gain from textual description of formula is limited. People do not have prior knowledge tend to find textual description distracting and confusing. Overly simplified text is subject to ambiguity.

2. Static plots of the formula provide students with more intuition of the formula. Students are able to capture more static features of the formula such as the general shape the function and the position of their maxes and mins.

3. Visualizations themselves (curves) aid students’ understanding, whereas labels and other textual elements in static plots will perplex students if they are not carefully written.

4. Interactive plots enable students to discover the dynamic features of the formula which are hidden in textual descriptions and static plots. Especially how the curves will vary their shape when certain parameters are changed and how much dependency the formula has on each parameter.

5. Students are sensitive to the color coding of each line. Also, the slight lagging in manipulating the plots also concerns students.

**Recommendations**

Following our conclusions, we propose several recommendations below to aid the visualization design:

1. Textual descriptions should be detailed so as not to perplex students and cause misinterpretation. The brief textual description should be avoided.

2. Static plots should be carefully annotated. This is especially true to critical points such as maxes and mins. They should be labeled with their specific values to draw students’ attention to them.

3. In static plots, the shape-determinant parameters should be carefully chosen to ensure that students can grasp the general shape of the formula instead of very specific ones.

4. In interactive plots, the allowed variation range of each parameter should be set individually as each parameter impacts the visualization differently.

5. In designing interactive plots, much effort should be made to choose appropriate color coding and avoid the lagging in interaction.

6. A larger extent of interaction is favored. In addition to varying shape-determinant parameters of each curve, functionalities such as hovering cursors on the plot to read function values should be considered.

**Conclusions**

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