Leveraging Transdisciplinary Engineering in a Changing and Connected World
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Team Decision Making Considering Uncertainty in Data Visualisation

Ainoa ABELLA [a,1], Midori SUGIHARA [b], Vanja ČOK [c], Tomiya KIMURA [b], Testuya TOMA [b], Jonathan CHACÓN [a]
[a] *Elisava, Barcelona School of Design and Engineering (UVIC-UCC), Spain*
[b] *Keio University, Japan*
[c] *University of Ljubljana, Slovenia*

Abstract. Information and data visualisation are powerful tools in order to present results and make decisions. In order to understand how data visualisation may change the group decision-making depending on the graphs seen by the participating members, we created a case study in two different contexts (Spain-Japan). In which, students have to make decisions to manage a small business. For example, to agree on how to run a bakery: total number of loaves to be made, the price at which it has to be sold, and the number of doughs to be made for the next day. Students will participate in a series of rounds where they are asked to: 1) write individually how they would run the business; 2) in groups they decide and discuss the different ideas and what decisions they make regarding the mentioned variables (price, loaves and doughs); 3) the teacher performs a simulation with the students' data and shows the results using tables; 4) Individually, write if what was done was different from what they proposed and explain what they had done differently. After completing some rounds, students are asked to participate again, but this time in step 3 they are given a graph instead of a table. In this way, we can see if there are significant differences when making decisions based on graphs or tables. In the light of the results, some design decisions and recommendations could be provided to teachers to improve decision making activities related to engineering education and new transdisciplinary fields.

Keywords. Group decision, Data interpretation, Decision making, Business case study

Introduction

In the current digital age, data has taken new importance and value [1]. Data has become part of our day to day with its advantages and disadvantages. The amount of data that can be collected and generated is enormous, according to some websites in 2023 3.5 quintillion bytes of data are created every day [2].

In this context of infoxication and uncertainty, it is necessary to have tools, procedures or resources that help to quickly verify, process and analyze this information to optimize decision-making.

As the authors indicate [3] data visualization has positioned itself as a very powerful tool to visually synthesize information in tables and graphs. On one hand, these visual representations allow a large amount of data to be summarized, it makes it easier for all

[1] Corresponding Author, Mail: aabella@elisava.net.

professionals with different backgrounds and for the general public to understand the content represented in it. On the other hand, this facilitates collaborative and multidisciplinary work since communication can be more fluent, and at the same time, promote more agile and consensual decision-making. One of the reasons is that it allows to integrate and visualize data from diverse data sources to see how they interact.

One of the main skills that new professionals and students need to develop is to work in an uncertain context, to make quick decisions and collaborate with different disciplines. This implies the use of mixed methodologies for achieving the objective, in which natural sciences, engineering and social sciences are merged, giving visibility to transdisciplinary engineering. Transdisciplinary engineering as a definition gained wide attention in 1987 [4]. Since then it is used to tackle the problems of society that seem to increasingly be more complex and interdependent. In other words, problems are not isolated to specific sectors or disciplines and they look like they are not predictable at all anymore.

As some authors mentioned transdisciplinarity could be a form of action and an attitude, and it is virtual to future prospects [5].

Some toolkits and case studies are developed in order to apply this transdisciplinary approach. For example, the Data Collection Toolkit [6] was created with its fundamentals in statics and statistics engineering to help designers to prepare optimal design experiments in the field of humanities and social sciences. Keena et al. [7] presented a case study of interdisciplinary decision making in the context of environmental science. The researchers presented an interactive tool that integrates data from multiple sources to support decision-making related to forest management. They emphasized the importance of interdisciplinary collaboration in developing effective decision support tools and highlighted the potential benefits of data visualisation to facilitate communication and understanding across disciplinary boundaries. Furthermore, transdisciplinarity is not limited to recognizing the interactions or mutualities between specialized research, but locates these interactions in an overall system without stable boundaries between disciplines [10][11][12][13] . Still, there are a number of problems with data visualization in transdisciplinary teams. The researchers mentioned a case study in which the company managed to develop a technical solution to ensure the provision of information for teamwork, but this solution was unusable. It was not based on the conditions corresponding to the social factors that constitute the operational environment for the solution [14].

As mentioned before, new challenges are related to more complexity, connectivity, and also with fluent collaboration. These attitudes and skills are key elements for personal and professional development, so, in order to apply transdisciplinarity engineering we have run a case study. The aim was to understand how data visualization could help to facilitate team decision making. To do so we have conducted as an experimental setup the same workshop titled Bakery Game in two different countries Japan and Spain. Each group of students have played this game twice, the first time using data and tabular and the second one they have as an option to visualize graphs with the main results. This study shows that visualization is effective as a common language for people with various backgrounds. And also, that visualization is an effective tool to make decisions and supports decision-making that encompasses stakeholders. So this is relevant for transdisciplinary-engineering.

1. Bakery Game Scenario

1.1. Aim of Bakery Game

The case study selected, with an innovative design of experiment, used as a scenario the Bakery Game [8] [9] . This tool allows students to simulate they own a bakery and as managers, they should determine every day three decisions to increase the surplus by making a profit:

1. The price of bread to be sold each day (currently, the market price is a key element). It must be between 2-7 euros (300-500 yen).
2. The number of loaves to be manufactured each day to be sold the day after. It must be between 0 and 500.
3. The number of loaves of dough to be ordered each day to be delivered the day after. It must be between 0 and 500.

To make decisions, first, it is important to properly know all processes of running the bakery from ordering to selling. After that, figure out the strategies for the production, material cost and their risks for loss -out of stock, unsold items, etc.-. With all this in mind, students have to take into account the business objective and decide the three mentioned items -selling price, production order and materials procedure-.

Once the decision is introduced in the Input Page (see Figure 1), and after running the simulation, each team could explore the result message:

1. The retained earnings of the top team are shown. Students do not know which team is on top, except if they are there themselves. However, they recognise the difference when they compare it to their retained earnings.
2. The selling price of each shop and the number of those who come to each shop is displayed. They can analyze the sensitivity of this market to forecast the corresponding to selling price.
3. Other information is delivered related to company status, cash flow, income statement, balance sheet.

Every time a round is finished, students look up the result message and later on they can introduce a new strategy (new input) for the next day.

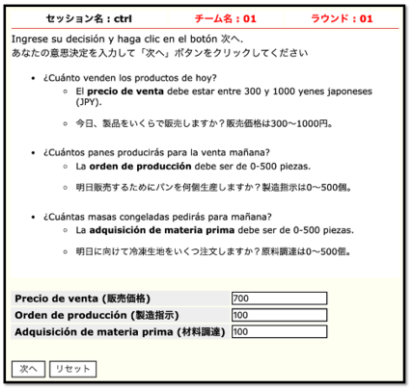

Figure 1. Screen to Input decision-making.

It is important to mention that teachers conducted the experiment by following instructions and steps and solving some questions. They only focused on answering topics related to the software, not on the decision process or team strategies. Apart from that they assured a proper atmosphere and that all teams play the same rules, but they didn't infer each group strategy.

2. Methodology

2.1. Case study context

In the current paper, two different countries have run at the same time the Bakery Game Scenario to understand how data visualization could help to facilitate team decision making and see if cultural differences have any influence on it.

A group of volunteer students have participated from two universities, (blinded for review) and (blinded for review) to see some potential transdisciplinary because they have different backgrounds.

As an experimental case study, a total of 7 students - 4 females and 3 men- of engineering in industrial design, were divided into 2 pairs and a team of 3 participants in Spain. And a total of 12 students - 5 females and 7 men of various education backgrounds (Machinery Engineering, Foreign language, Law, Data science etc.) divided into 3 pairs and a team of 4 participants in Japan(Figure2-3). All students were guided, step by step, by two teachers during the workshop.

At first, confirm of experimental agreement, and sign the experimental agreement. Then, answer to example questions to check the data visualization literacy. And the bakery game scenario description, then one trial round conducted start the game. At the game, the participants have to make a decision of selling price of the bread, production instruction and procurement of material. After the game, answer the questionnaire. And the Ethics application submitted to and accepted by the Graduate School of System Design and Management, Keio University. Approval number #SDM-2023-E005.

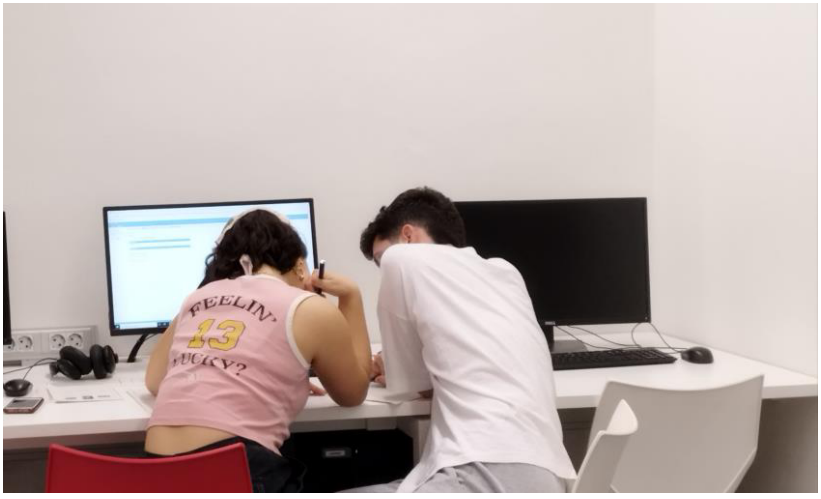

Figure 2. Participants discussing the strategy for the workshop.

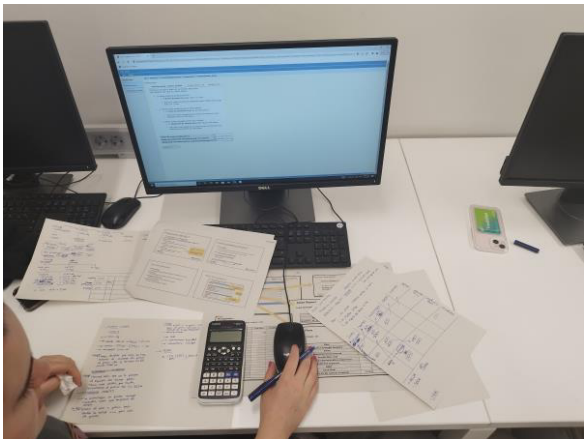

Figure 3. Example of materials and notes that participants used to make group decisions.

3. Result

3.1. The result of Surplus

The result of surplus shows the tendencies for the results of bakery games in (blinded for review) (Spain) and (blinded for review) (Japan). First, an example set by each team accounts for the surplus. Figure 4 shows the surplus change for Spain and Figure 5 shows the surplus change for Japan. The left side of the graph shows the results of the decision-making process when looking at the tabular format, and the right side shows the results of the decision-making process when looking at the graphical format.

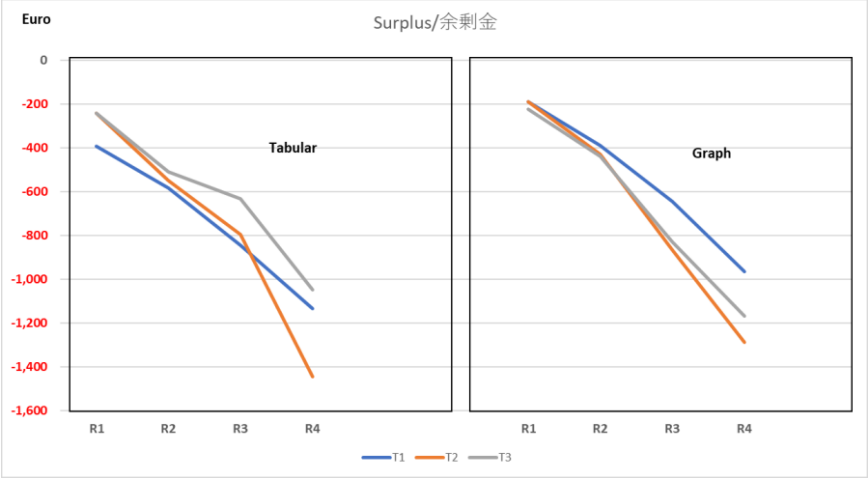

Figure 4. Surplus Transition in Spain.

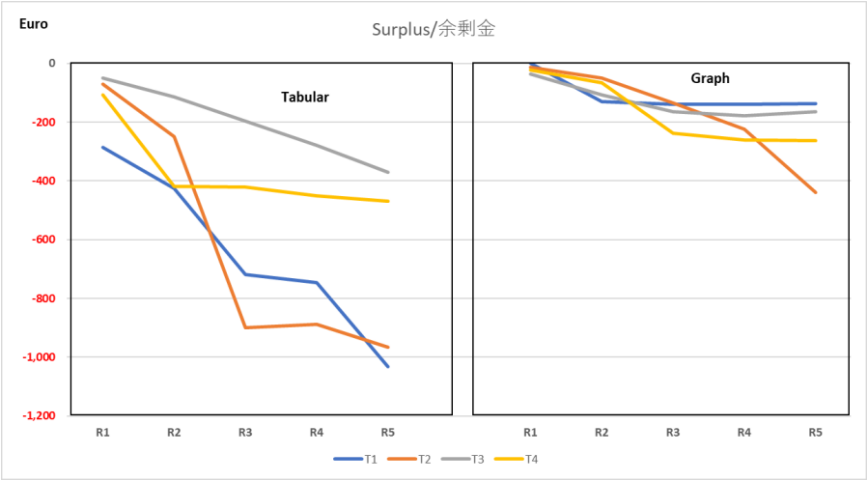

Figure 5. Surplus Transition in Japan.

3.2. Each teams' opinion from discussion

Examples of the representative opinions of each team for each round regarding the pricing of this round are shown below. An example of a Spanish opinion is shown in Table 1 and an example of a Japanese opinion is shown in Table 2.

Table 1. Representative opinion from discussion in Spain.

Style	Round	Opinion
Tabular	1	We have decided by mutual agreement to set a high price and bake 100 loaves. Price 7 euros.
	2	We have seen that the team with the lowest price has more visits, therefore we will lower the price from 7 to 3.52 euros.
	3	Strategy to be able to get more customers, we lower the price to 3 euros.We have bought fewer loaves because we did not have many customers.
	4	We set the price at 3,5 euros.
Graph	1	As we have seen in the previous test that setting very low prices does not work, we decided to set an intermediate price. We sell the 100 loaves as planned and bake less so as not to throw anything away.
	2	We raise the price because we already have customers to earn a little more money. We asked for 70 loaves to keep 100 and bake the last day.
	3	We bake 100 and buy 0. We gradually raise prices to 4.5 euros because we already have customers. We anticipate buying more loaves tomorrow since we would spend without selling.
	4	We sell the 100 loaves for 5 euros since we did well the day before and even if we do not attract customers we have no other option to sell them another day.

Table 2. Representative opinion from discussion in Japan.

Style	Round	Opinion
Tabular	1	I followed a strong member. Since it was the first time, I decided without much strategy.
	2	I followed the group's intention because I was convinced that procurement of raw materials was unnecessary.
	3	I was out of balance between procurement of raw materials and manufacturing, so I followed the group's intention.
	4	Followed another member's opinion because I felt it was better.
	5	Followed because I was convinced by the opinions of others
Graph	1	There was not much difference between the other members, agreed with them.
	2	The opinions of other members were in agreement.
	3	Almost the same opinion.
	4	The opinions of the three members were in agreement.
	5	Followed the group's opinion.

3.3. Difference between Team Decision-Making and Individual Decision-Making

Finally, Figure 6 shows the results of the tabular view of the sales price initially set by each individual member of Japanese Team 1 and the price decided by the team, and Figure 7 shows the results of the graphical view of the results.

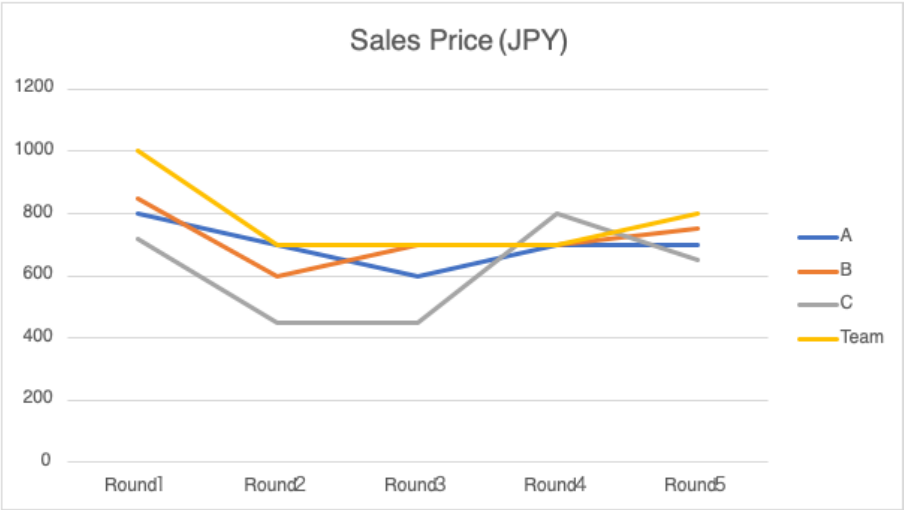

Figure 6. Sales Price trends for Japanese Team1 in Tabular Format.

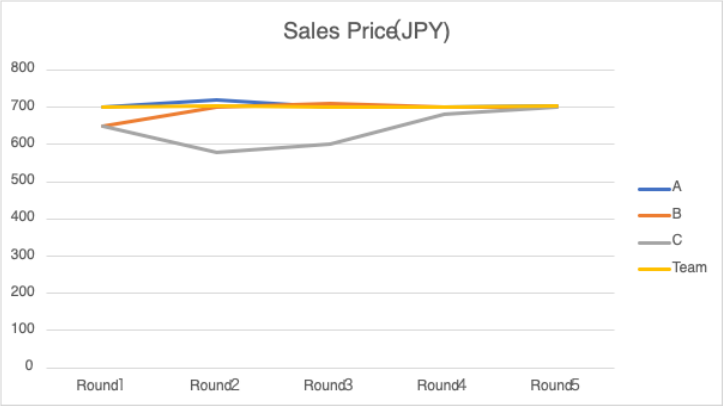

Figure 7. Sales Price trends for Japanese Team1 in Graph Format.

4. Discussion, Conclusion and Limitation

Managing a business deals with various complex variables. This task requires a combination of skills from disciplines such as economics and resource management, which can be challenging for people unfamiliar with either field. In this study, we focused on only three variables: the daily sales price of bread, the number of doughs to be processed that day and the number of frozen doughs for the following day and prepared two scenarios for testing if graphics could support participants to take faster decisions than tables.

During the Spanish case study, we observed that the time allotted for making group decisions had an impact on the results. The students were given time to make individual decisions, followed by a period for group discussion and consensus building before moving on to the next phase. We assumed that the graph phase, where information could be quickly interpreted, would yield faster results compared to the table phase. However, due to the complexity of the case, the expected outcome was not conclusively observed. It would be valuable to conduct the case study with a larger number of students, allowing for more time for individual and group decision-making, as well as documenting decisions in greater detail throughout the process.

Taking in consideration the three main elements of the study: sales price, number of doughs to bake and number of frozen doughs to receive the following day. There is some evidence that, both in the Spanish and Japanese teams, one of them has more extreme results in the tabular scenario. While in the scenario with graphs the results are not so extreme and have a clear trend, either decreasing or increasing. It should be noted that, in the case of the Japanese scenario, two of the teams that performed better, economically speaking, keeping the price constant or almost constant during all iterations in the graphics scenario.

In the case of production, the results about the use of graphics are not conclusive. Both in the tabular and graphic scenarios, the participation of the different teams, both Japanese and Spanish, followed different strategies. There are teams that produce all the material while others maintain their stock constant around a given number. Although

they were allowed to buy up to 500 frozen doughs per round, few teams ever produce that much material or invest that much in raw materials.

The difference between Spain and Japan in terms of surplus money in this study may have been due to the fact that the participants in Spain were undergraduate students, while the participants in Japan were working master's students. It is also possible that the Spanish undergraduates did not have a good understanding of the pricing for the high-end bread setting. And then, Japanese students are working students, and because of the difference in working experience, it is possible that those with more experience were followed by those with less experience. On the other hand, Spanish students are undergraduates, so they have similar experience and may have discussed and made decisions as a group.

Regarding participants, in the results it has been possible to appreciate a difference between the youngest students in Spain, and the most mature students in Japan. However, in both cases the results show a less negative slope when graphs are used than when tables are used. And both scenarios show a tendency for teams to raise the price of the product in the final iterations. In addition, during group discussions, having a visual representation of information helped to share ideas and justify their decision making. Evidencing that the age or degree of maturity of the participants is a factor that influences the speed of reading and using the data. In addition, when making decisions through group discussion, Spanish students tend to make decisions through discussion, while Japanese students seem to tend to follow the opinions of those who have experience or those who offer plausible opinions. Also, when making decisions as a team, if there is no difference between each person's opinion and the team's opinion, and if both sides respect each other's opinion, good results may be produced.

However, the number of participants was small this time, so it is possible that such a difference in attributes was caused by the small number of participants, but by increasing the number of participants, results may be obtained that do not rely on attributes. If differences between the two countries are to be examined in the future, the number of participants needs to be increased.

This first iteration shows signs of how graphics can help group decision making, especially when it comes to supporting the actions taken. As future work, the study could be repeated with a larger number of students. Agreeing on better times for each of the phases. The comparison between students of different ages and of different nationalities has also yielded differences in the observations that would be interesting to work on in future collaborations.

Acknowledgement

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