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RESEARCH ARTICLE

How to teach Data Visualisation to Fresh Statisticians: A Case Study in Turkey

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ABSTRACT
This article presents the content, objectives, and student opinions regarding the first-year compulsory data processing and visualisation course taught in English, which is the first of its kind in Turkey. After exploring the academic and industrial applications of data visualisation and examining the tools used, the article highlights that the content developed was well-received by students. It was observed that all students developed a positive attitude towards data visualisation by the end of the semester. The students particularly enjoyed the group project, which involved data analysis and reporting using the Python programming language, as it allowed them to apply the data processing and visualisation steps and create a data analysis report.

Keywords: Statistics Education Research, Data Visualisation, Curriculum, Data Science Education

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Introduction

Tufte (2001) defines data visualisation, which has multiple definitions in the literature, as "the graphic display of quantitative information". The modern form of data visualisation, which began with cave paintings in ancient times, dates back to the 1700s. William Playfair's visualisation of England's balance of trade in his book "Commercial and Political Atlas" published in 1786 is perhaps what has earned him the title of "the father of statistical presentation" today (Figure 1). The bar plot, line plot, and later introduced circle and pie charts by Playfair are still used today. Similarly, Florence Nightingale's created graphs, which are still used, also hold an important place in the history of data visualisation.

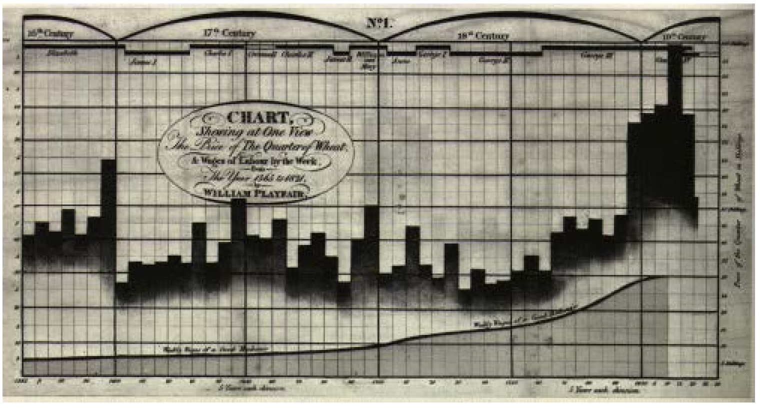

Figure 1. *Time Series Plot Created by W. Playfair*

Friendly et al. (2008) stated that the increase in the number of collected and organised data through the establishment of statistical offices in Europe starting from the 1850s, along with the development of statistical theories proposed by Gauss and Laplace to obtain meaningful results from data, marked the golden age of data visualisation. However, this momentum faded in the early 1900s and gave way to a period known as the "modern dark age" that lasted until the 1950s.

According to Friendly et al. (2008), there are three developments that concluded this approximately 50-year period and ushered in the rebirth of data visualisation:

- John W. Tukey's article "The Future of Data Analysis," published in 1962.
- Jacques Bertin's book "Semiologie Graphique," published in 1967 (Bertin, 1967).
- The emergence of FORTRAN, the first high-level language for computing that enabled the processing of statistical data in a computer environment.

Following these three developments, the increasing amount of data that needs to be interpreted and the emergence of software and programming languages suitable for data visualisation, along with technological advancements, have not only led to the use of data visualisation in various fields such as journalism, academia, and design but also transformed it into an interdisciplinary domain. Particularly during the COVID-19 period, the importance of data visualisation, which has become ubiquitous in our daily lives, has been underscored once again, resembling a hand sanitiser.

Currently, in universities, particularly in Turkey, data visualisation is taught as a subtopic in undergraduate statistics programmes as a tool for exploring data not explaining it, but it does not provide details about the storytelling aspect, which is the true power and allure of data visualisation. Questions with relevance in both academia and industry, such as how to use colour and text effectively in an ideal visual, where components like axes and legends should be positioned, and which strategies can better convey a message to the audience, remain unanswered in the existing curricula. There are not many studies on the Data Visualisation Course curriculum design for university students. Urness (2016) examined the difficulties associated with instructing a foundational course in computer graphics and provided suggestions for integrating a module focused on data visualisation. In place of a course centred solely on programming, the course introduced an alternative curriculum that encompasses diverse subjects, encompassing a module dedicated to data visualisation using Tableau, D3, processing, and Python libraries such as plotlib. The course only focuses on visualisation, not on data preprocessing, cleaning, and tidying. Bandi and Fellah (2017) presented their new data visualisation course for computer science and data science majors, where the learning outcomes of the course were aligned for those of the tech industry. They designed the course with the collaboration of IT and data services professionals from the industry so it focuses on the industry needs only such as for business track performance and make strategic decisions and visualise customer data to understand customer behaviour and preferences, for healthcare visualise patient data to identify trends, patterns, and outliers to find a better treatment, or for the manufacturing visualise production data to identify bottlenecks, improve efficiency, and reduce costs. The course emphasises on both the technical and soft skill needs of the industry. Zentner et al. (2019) explored data visualisation literature, identifying themes shaping effective data dashboard development. Through a mixed methods approach with education professionals, it found that readability was tied to functionality, titles, colour, and layout—reinforcing literature themes and providing a framework for better data visualisation in education. Asamoah (2022) presented a curriculum for teaching basic and advanced data visualisation. The survey results show a preference for hands-on learning over theory, with participants rating the curriculum components and structure highly. The study explored key components for effectively teaching a data visualisation course, however, in the course, only

Tableau was used, not on the skills in data management and programming such as Python or SQL.

Students have traditionally learned data visualisation by drawing graphs, but now interactive and dynamic visualisation tools are increasingly used. Forber et al. (2014) discussed four such tools used in New Zealand classrooms: GenStat for Teaching and Learning Schools and Undergraduate (GTL), Auckland University's iNZight and VIT for bootstrapping and randomisation, and CAST e-books, all of which are publicly available and used internationally. Queiroz et. al. (2017) emphasises that interpreting data is a complex process involving cognitive, technical, contextual, and affective aspects. However, the affective aspects are under-discussed in the literature. They examined an empirical study on the influence of affective expression during data interpretation by final-year statistics and pedagogy undergraduates, revealing that affective expressions were the most frequent category used, despite differing academic backgrounds. Hudiburgh and Garbinsky (2020) created a semester-long group project for introductory statistics courses to enhance students' skills in developing and interpreting data visualisations. This project fosters hands-on learning, mathematical reasoning, and collaboration, and this article details its structure and assessment. Wilke (2019) argues that visualisation is an essential tool for data interpretation. He also provides several practical tips for creating effective data visualisations. For example, he recommends using simple and clear designs, avoiding clutter, and using colour and shading effectively.

A few examples of research on teaching visualisation in statistics education can be given. Garfield et al. (2000) conducted a study in which they compared the performance of two groups of students on a statistical test. One group received instruction in data visualisation, while the other group did not. The students who received instruction in data visualisation performed significantly better on the test. Gould and Gould (2005) developed a curriculum for teaching data visualisation to elementary school students. The curriculum includes lessons on various data visualisation techniques, such as bar charts, line charts, and histograms. The authors found that the curriculum was effective in improving students' understanding of data visualisation and their ability to interpret data. Nolan and Perrett (2016) emphasise the importance of incorporating statistical graphics into undergraduate statistics curricula through various assignments, such as deconstructing and reconstructing plots, copying masterful graphs, and creating interactive visualisations. It discusses the goals and details of each assignment, broader concepts in graphics, and the need for increased focus on statistical graphics at all educational levels. Providing students with detailed comments and a completed matrix of competencies fosters a discussion between the instructor and student that focuses more on the process and content than on the points. The survey of Firat et al. (2022) focuses comprehensively on interactive visualisation literacy, examining and categorising prior research on user understanding and discovering visual patterns. It provides an overview of the evaluation techniques, categorises research into unique groups, and identifies both mature and unexplored areas for future study, serving as a valuable resource for researchers at all levels.

In light of these studies, it can be concluded that visualisation can help students to better understand statistics, be more engaged in statistics lessons, develop critical thinking and problem-solving skills, and communicate their statistical findings more effectively.

This article aims to address the aforementioned issues and serve as an example for other statistics departments while keeping up with the requirements of the era. It will focus on the content of the STAT 112 course, titled "Data Processing and Visualisation," which was introduced as a compulsory course in the curriculum of first-year students at the Middle East Technical University Department of Statistics for the 2022-23 Fall semester, taught in English. Additionally, the Statistics Department at Eskişehir Technical University has opened a data visualisation course for its students. Although this course is not mandatory, it is taught in Turkish and has less intensity and a different subject matter compared to the aforementioned course. The authors aim to create a guide that reflects the content of this course, which is offered for the first time to first-year statistics students in English in Turkey, and the feedback received from students who have taken this course. This guide will serve as a reference and assistance for all departments, particularly those that have not yet offered a data visualisation course, not only in Turkey but also in other regions. Also, since there is a scarcity of shared academic experiences regarding data visualisation courses in the literature, the authors aim to contribute to closing this gap with this article.

The Course: Content, Target, Objective, Progress, and Materials

Target

The target group for the data processing and visualisation course, as stated in the introductory section, is first-year statistics students who have just started their undergraduate studies. Apart from their personal interests and studies, these students do not have solid programming and technical backgrounds. This course has been added to the curriculum of these students as a compulsory course. In the 2022-23 Fall semester, 88 students took this course.

Data visualisation is first introduced using Tableau, an easy-to-use software. Students learn the basics of Python in a parallel compulsory course, Introduction to Computer Programming. In the second half of the semester, students apply their Python knowledge to data handling and visualisation using Python libraries. Datacamp classrooms, which are free for educators and their students, are also used to help students catch up with any computational challenges.

Content and Objectives

The course content was designed based on criteria such as the most commonly used software in data visualisation, software used in the business world, and the students' theoretical and practical average knowledge level. The focus of the course is on fundamental principles and best practises for data manipulation and visualisation because most of the real data is not ready for the use of visualisation directly so we comprise both data manipulation and preparation and then create an efficient visual from these data. The course starts with basic concepts in statistics such as parameters, statistics, data types and appropriate summary statistics and visualisation types for univariate and multivariate analysis such as bar charts, histograms, scatter plots, treemap, and bubble charts. It is divided into two parts:

The first part focuses on basic concepts such as data types, data manipulation, and querying. The second part focuses on data visualisation, starting with exploratory data analysis using various statistical plots. The data manipulation and visualisation methods are demonstrated using Tableau, one of the top 10 data visualisation tools (Simplilearn, 2023), as well as the Flourish and Python packages, specifically plotlib and seaborne. Students will create their own data visualisations and learn to use open-source data visualisation tools.

The course begins with a brief introduction to data visualisation, covering its development and the Gestalt Principles, and the characteristics of effective visualisation techniques. In the second week, the focus shifts to data description and types, along with appropriate visualisation tools for each type, such as bar plots, box plots, violin plots, histograms, and scatter plots. Discussions include topics like colour separation, value representation by colour, and colour palettes in data visualisation. The third week introduces students to Tableau Public, followed by an exploration of basic data manipulation techniques in the fourth week, including selecting, sorting, filtering, summarising, and combining datasets using Tableau. In the fifth week, the course explains the steps for creating visualisations and preparing dashboards with Tableau, while the sixth week covers interactive plotting using Flourish. The seventh week teaches basic data manipulation using Python, with libraries like Numpy and Pandas, and continues into the eighth week with grouping and pivoting datasets using Python. In the ninth week, data quality was addressed, focusing on aspects such as validity, accuracy, completeness, consistency, and uniformity. The tenth week covers data cleaning and tidying, including techniques like recoding, character manipulation, converting dates, string normalisation, string matching, detecting and localising errors, deductive correction, and tidying messy data. During the eleventh week, students learn to deal with common problems like missing or inconsistent values in datasets using Python packages. Week 12 focuses on visualising data with basic plots and interpreting 1D distributions using Python libraries such as Matplotlib and Seaborn. The following week explores the visualisation and interpretation of multivariate data using Python libraries. Finally, the course concludes in the fourteenth week with practical exercises based on real-life examples to reinforce the concepts learned throughout the course.

We aim to achieve comprehensive objectives to provide students with a robust foundation in data visualisation. Students will learn about different data types and perform basic data operations using Tableau and Python, including data transformations such as aggregation and filtering, indexing, slicing, and subsetting in pandas DataFrames. The course offers practical experience in building and evaluating visualisation systems, as well as designing and creating data visualisations. Students will conduct exploratory data analysis using visualisation techniques and utilise the principles of the Grammar of Graphics to convert data into visual figures using seaborne and plotlib libraries. They will also identify potential challenges and pitfalls when working with data in Tableau and Python. The course emphasises the creation of basic and visually appealing diagrams using Tableau and Python, and the organisation of visual presentations of data for effective communication. Additionally, students will prepare dashboards and develop storytelling techniques to impress specific audiences. The design and evaluation of colour palettes for visualisation based on the principles of perception are also covered. Finally, students will identify opportunities for the application of data visualisation in various domains, ensuring that they can apply their skills in various domains.

The class was conducted through in-class lessons, recitation hours for exercises with real-life examples, two projects (one using Tableau to do data cleaning/tidying, EDA, and preparing an impressive dashboard by themselves using the same dataset so there were 88 different EDA and dashboard design, and the other using Python to do cleaning and do EDA with excellent visualisations with a group of 5 students), and one in-class midterm exam.

We prefer Tableau because it is a user-friendly data visualisation tool that does not require any prior programming knowledge. This makes it a good choice for students who are just starting to learn about data visualisation. Moreover, Python is a versatile programming language that can be used for various data tasks, including data cleaning, preprocessing, and visualisation. It is also a popular language for data science and machine learning. Tableau and Python can be used together to create powerful and informative data visualisations. For example, students can use Tableau to create interactive dashboards and Python to create custom visualisations. These are the most important reasons to decide on using these tools in the course.

The grammar of graphics is a set of principles for creating effective data visualisations. It provides a framework for thinking about the different elements of a visualisation, such as data, marks, channels, and aesthetics. Hence, the specific capabilities of the computing platform may affect the way that the grammar of the graphics is implemented. Some computing platforms may have limitations on data encoding, interaction, and output formats, such as the use of certain colour palettes or mark types, interaction techniques, or export to certain file formats.

Students have almost a month to complete their first project, which is an individual report on the EDA and Tableau dashboards. For their second project, students worked in groups to complete data cleaning and tidying, create EDA, and answer research questions using descriptive statistics, tables, or visualisations in a month. In their reports and visualisations, students are expected to follow the Gestalt principles and grammar of the graphics principles.

Progress and Materials

To encourage students to build their own data science portfolios and showcase their future projects, a GitHub account for the course was created, which includes recitation notes, various data visualisation resources, and introductory examples of pandas and NumPy for Python (https://github.com/MetuStat112). Additionally, an associated GitHub-hosted website was created (https://metustat112.github.io/) to serve as a repository for course materials.

After introducing the basics of data types, relevant visualisation types, and their interpretation in both class and recitation hours, students were given real-life datasets to perform data preprocessing and cleaning using Tableau Public and SQL commands. They were then tasked with creating visualisations based on these cleaned datasets and learning the fundamentals of exploratory data analysis (EDA).

Over a span of seven weeks, the course covered topics such as data usage in visualisations, colour usage, and Gestalt Principles, as well as practical applications using Tableau. For the project, students were provided with the New York City Airbnb Open Data from Kaggle. They were asked to clean the dataset, address issues such as user-based errors, lowercase/uppercase inconsistencies, and missing values, and then create a dashboard using Tableau to highlight a topic of their choice. The dashboards published on Tableau Public were compiled and shared on the course's GitHub-hosted website https://metustat112.github.io/airbnb_dashboard.html. One of the dashboards created by a student who took the course is shown in Figure 2.

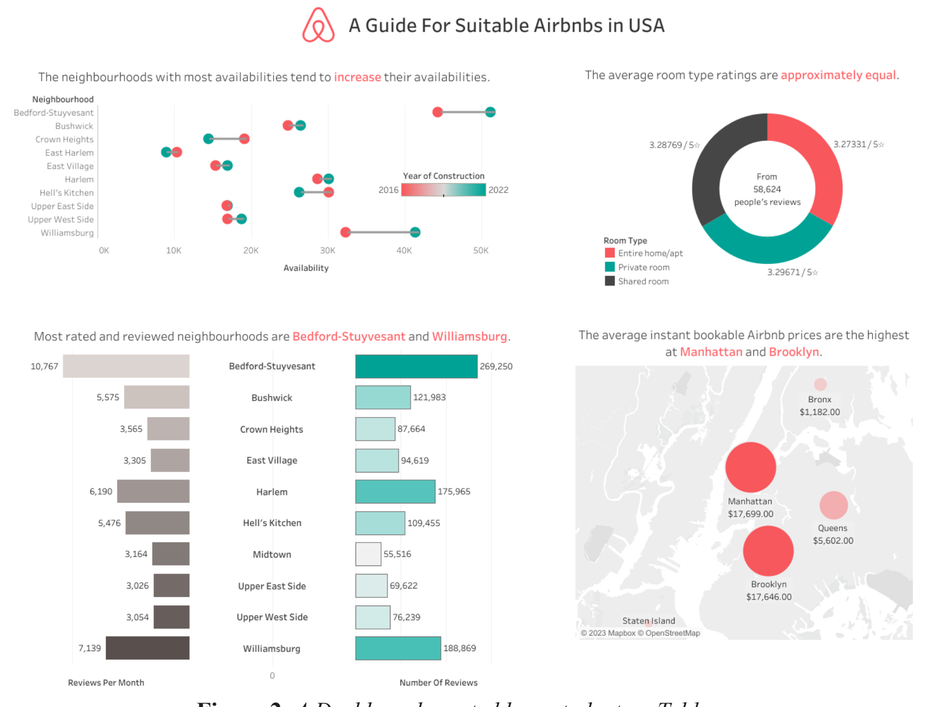

Figure 2. *A Dashboard created by a student on Tableau*

Starting from the second half of the semester (Week 7), the course transitioned to the Python programming language. After introducing commonly used packages and applications for data manipulation, such as NumPy and pandas, students were given a dirty dataset to clean. In addition, basic statistical calculations such as mean, median, mode, standard deviation, and correlation were demonstrated in Python. Visualisation techniques using the plotlib and seaborne packages were explored, along with strategies to improve the visual quality of the graphs produced with these packages.

In the final class, a data visualization expert delivered a presentation to expose students to real-life examples of data visualisation and storytelling.

During the semester, DataCamp for Classrooms was provided to students, and several courses or chapters were assigned as homework assignments related to the topics covered in the class.

At the end of the semester, a group projects conducted to assess and measure students' knowledge and skills in data processing, visualisation, and basic statistics. Students were given a 16-step checklist to follow for data cleaning and tidying. Then, students were divided into groups of 4-5 individuals and provided with synthetic and dirty datasets based on fictional scenarios such as housing prices in Ankara, salary of non-existing NBA players, and exam scores of the non-existing students from nonexistent high school. We aim to help students apply all the techniques that we learned, and it is difficult and time consuming to find the real datasets compromising all the problems separately. This is the main reason for our choice regarding the synthetic data. In these datasets, both categorical and continuous variables are incorporated. These datasets include randomly introduced missing observations and outlier values. Students were required to clean the data, fix the problems, answer 6-8 research questions that they created using visualisations and statistics, and write a 10-page report. Furthermore, to assess the fairness of the group work, all group members were required to write a reflection report. In this report, they answered the following questions:

- What were your overall feelings about this project?
- Did this project help you understand the data preprocessing and visualisation steps in data analysis any better?
- How did your group work together? How many times did you meet to discuss the project? Were the meetings online or face-to-face? Usually, how long do the meetings take?
- What was your role in the group?
- Were there any group members who did not pull their weight? Any group members who tried bossing the group around?

In their reflective reports, students commonly expressed a sense of relief and found the concept of a final project, instead of a final exam, to be beneficial. They highlighted that the project facilitated their understanding of the importance of data organisation, cleaning, and subsequent visualisation—the essential stages of a real-life data visualisation process. Additionally, they discussed the benefits and challenges of teamwork, elaborating on the tasks they undertook both as a team and individually within their groups.

There were very few students who did not join the project meetings and did not give any effort to the project, so they failed the class. The grade distributions of the students are given in the following table (Table 1).

Table 1. *The grade distribution of students*

AA	BA	BB	CB	CC	DC	DD	FD	FF	NA
28	11	14	10	1	6	9	5	1	3

Approximately 60% of the students achieved a grade of BB (3.0 out of 4.0) or higher at the end of the semester.

Student Insights

At the end of the semester, a questionnaire was given to the students, and feedback was collected from some of the students who took the course for the first time, aiming to gain a general understanding of the effectiveness of the course. During this feedback process, students' identities were kept confidential to prevent bias in the results.

The following graph illustrates the overall attitude of students towards the course. Students were asked to rate the course on a scale of 1 to 10, and it was observed that the average score given by students was 8.3 out of 10. This indicates that the teaching above-mentioned approach had a positive impact on the students (Figure 3).

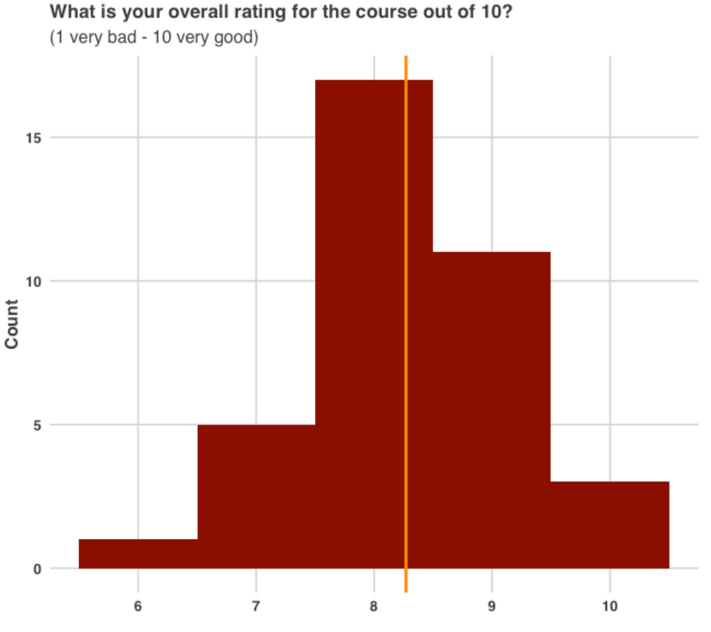

Figure 3. *Overall Rating of the Course, according to students*

Another result that supports this positive impact is shown in the graph below, which depicts the difference between students' perceptions of data visualisation before and after taking the course. While almost half of the students did not have a positive perception of data visualisation before taking the course, it is evident that this situation changed by the end of the semester (Figure 4).

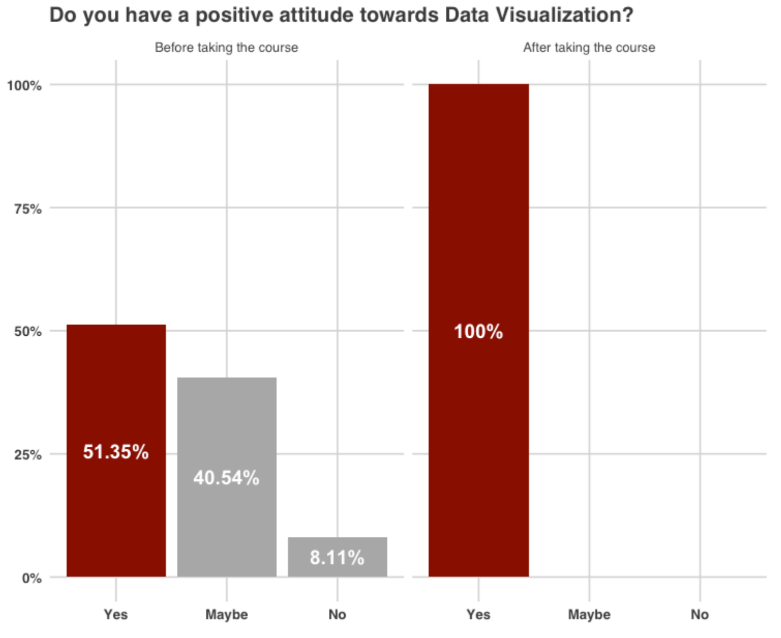

Figure 4. *The Attitude of the Students on Data Visualisation before the course and after the course*

The fact that students mentioned finding the course helpful is another piece of evidence supporting this positive impact (Figure 5).

Figure 5. *The words that students have used to describe the course*

Approximately 60% of the students who took the course expressed satisfaction with both the Tableau and Python components, while 32% specifically mentioned being satisfied with Tableau, and 10% expressed satisfaction with Python. However, when students were asked which project they found beneficial, the majority preferred the project involving Python, which included coding and reporting (Figure 6).

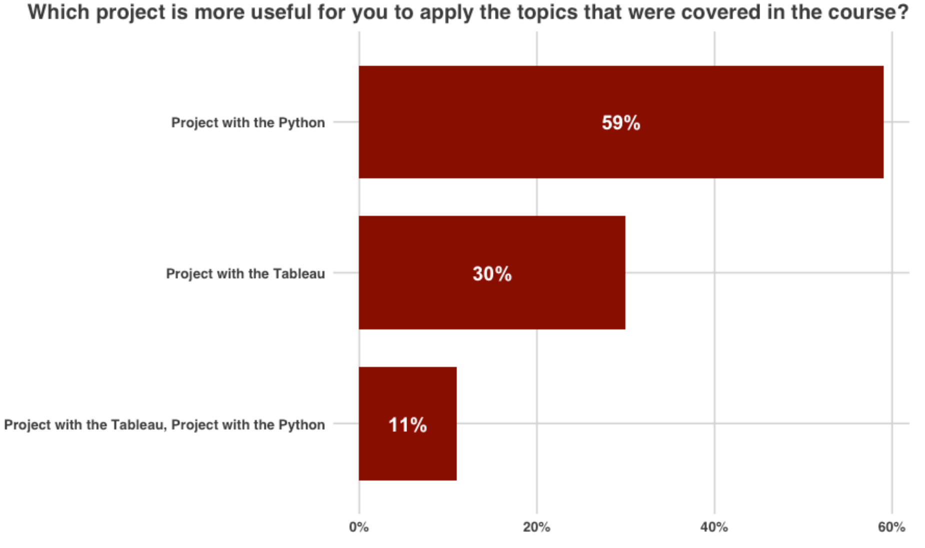

Figure 6. *The breakdown of students' preferences for their favourite part of the course*

When students were asked questions on a 5-point Likert scale to assess their overall thoughts on the course, it was generally observed that they had positive opinions (Figure 7). However, it was also noted that there was a group of students who did not consider the course academically challenging.

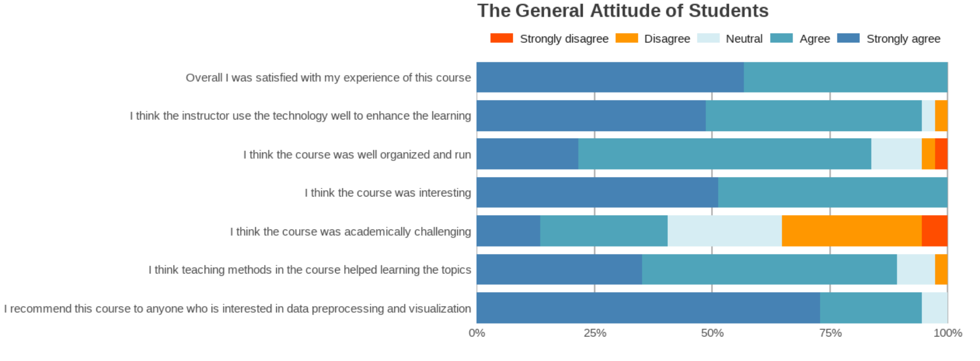

Figure 7. *The distribution of the students by the part of the course that they liked most.*

Conclusion

We provided guidance to educators aspiring to design a data cleansing and visualisation course with this article. Our journey through this lecture design has underscored the importance of data integrity, emphasising that the quality of analysis and visualisation hinges upon the accuracy and reliability of the underlying data.

Throughout this course, students were immersed in the dynamic interplay between raw data and meaningful insights, mastering techniques that unveil concealed patterns and narratives. This skill set not only hinges on data integrity but also encompasses the artistry of impactful visualisation. By mastering techniques ranging from data cleaning and transformation to advanced visualisation tools, students have gained a multifaceted toolkit that empowers them to unravel complexity and present it in a digestible and engaging manner.

The importance of data integrity and visualisation is well-documented in the literature. According to Kandel et al. (2011), data wrangling is crucial for exploratory data analysis and achieving accurate results. Similarly, Heer, et. al. (2010) emphasise that effective data visualisation enables users to understand and communicate complex data relationships.

As the digital landscape continues to expand, the ability to manipulate and visualise data with precision and creativity has become an indispensable skill across disciplines. This lecture design serves as a launch for future explorations, equipping students with the acumen to navigate the dynamic world of data-driven decision-making and storytelling. This lecture design not only imparts technical expertise but also nurtures qualities such as attention to detail, critical thinking, and the ability to convey complex ideas lucidly.

In a world where data drives decision-making, these skills stand as pillars of competence. The ability to navigate complex datasets, distil meaningful information, and present it visually is a coveted asset across disciplines. Companies and industries recognise the value of employees who can extract actionable knowledge from data, and academia benefits from researchers who can convey complex concepts in accessible formats.

Chen et. al. (2017) noted that the ability to present data visually is not only about technical skills but also about storytelling and communication. Few (2006) argues that effective data visualisation can lead to better decision-making and insights.

Students depart with more than technical prowess—they depart as storytellers who can navigate the intricacies of data and present it with impact. Armed with Tableau, Python, and a profound understanding of data's visual language, they are poised to excel, shaping the landscape of both academia and industry with their data-driven insights.

At the end of the course, based on the conducted surveys, all students were satisfied with the course. The majority of them also recognised the efficient use of technology to improve learning levels. Moreover, most of the students believed that the curriculum explained above was well-organised and interesting and could be recommended to anyone willing to learn data visualisation. However, it is seen that they did not agree with the idea that the course context was academically challenging, which might be the point that should be improved for the following semesters. Another interesting result is that more than half of the students found the project with Python more useful than the one with Tableau. This may imply that students would prefer to start the data visualisation process from scratch rather than play with the prepared data and go beyond the limitations of drag-and-drop software like Tableau. Based on this feedback, the course content may be modified to maintain the balance between Python and Tableau.

The literature also supports the the preference for Python over Tableau among students. Python's extensive libraries and flexibility allow for deeper data manipulation and complex visualisations which are often required in advanced data science tasks. This is in contrast to Tableau's user-friendly interface, which, while excellent for creating quick visualisations, can be limited in terms of customisation and complex data processing capabilities (MindBowser, 2023; DataCamp, 2023). This distinction highlights the necessity for educators to balance both tools in their curriculum to cater to diverse learning needs and professional applications.

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Peer-review: Externally peer-reviewed.

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