Effective Visualization Techniques for Multi-Dimensional Student Performance Data

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***Abstract*—During a time of relentless march of educational standards and the ever-increasing demands of a globally connected society, individuals persistently seek pathways to enhance educational well-being by assessing holistically. The changes brought about by various means in the modern education system make it imperative for us to personalize a student's learning experience for better understanding and to keep up with changing times. After a thorough literature review and observations from multiple correlated case studies, we could envision the potential of the use of effective Data Visualization practices and techniques in analyzing a student's performance and helping them improve both academically and personally. It studies the overall impact of various factors on student performance and how innovative and intuitive methods can be devised to come up with insightful and informative visuals which can help students make the right decisions. By using innovative visualization techniques, educational institutions and professionals can discover patterns, trends, and actionable insights within student performance data, helping perform timely and helpful interventions and tailor a student's learning experiences as per their preferences and observations from collected data. This paper investigates current visualization practices and suggests the adoption of more intuitive and advanced visualization techniques and practices to traverse the complexities of multi-dimensional student performance data effectively. With a focus on clarity, usability, and understandability, these visualizations assist educators in making data and insight driven decisions, stimulate a betterment of instructions, and help students enhance their overall performance through tailor made visuals and insights.**

Keywords: Academic and personal growth, Data-driven insights, Data visualization, Effective visualization practices, Enhanced student performance, Holistic evaluation, Multi-dimensional data, Personalized learning experiences, Tailored visuals.

I. INTRODUCTION

In the forever changing landscape of education, where the standards shift continuously with the increase in the demands of our globally interconnected society, the desire
to make education better. Nowadays, while we assess a student's performance, we don't just look at their grades anymore, we instead try to understand a student better, this includes finding what a student is good at, where they're lacking and how they could learn the best. As the educational institutions and professionals try to enhance the learning experiences of each student, the role of data analysis becomes very important.

In these prevailing conditions, the use of effective and insightful data visualization techniques and practices presents itself as a mighty tool for better understanding, comprehension and eventual improvement in student performance. Through an expansive literature review and evaluation and observation of pertinent case studies, this paper aims to investigate the potential of utilizing intuitive data visualization practices to analyze student performance data. By making use of insights garnered from various sources, educational institutes can gain a deeper understanding of the variables and factors affecting student performance and personalize instructions and guidance accordingly.

The visualization techniques and tools proposed in this paper come to the aid of both the educators and the students alike due to their ease to use, understanding and clarity. Transforming the complex datasets related to a student's progress into insightful and easy to understand visuals help the educators to make insights-driven decisions, improving the learning experiences which results in enhanced student performances. By using visuals which are

personalized and give useful insights, everyone involved in education can start doing things better and adapt more quickly to what would work best for the student.

This paper takes a detailed approach to studying the magnitude of the impact of various factors on student performance and suggests putting into practice effective and intuitive data visualization techniques. By presenting data in insightful and easily comprehensible forms, educational institutions and professionals can discover trends, patterns and workable insights from multi-faceted student performance data. Such visuals not only ease the data driven decision making process, but also empower both educators and students alike to refine their instructions, strategies and methods respectively to make the student's academic journey more enjoyable and fruitful.

In this paper, we will explore and analyze current visualization techniques and practices in the field of education to identify their shortcomings, limitations and possible downsides and suggest potential solutions and strategies to adopting more innovative and insightful visualization practices. We will then explore how these current practices affect the decision making process and compare the impact with that of the proposed techniques. By utilizing the potential of data visualization practices, we aim to help education professionals and institutions choose the right tools and strategies to deal with the complexities of student data effectively and gain workable insights to meaningfully impact and improve their performance.

II. LITERATURE REVIEW

In the chase for enhancing student performance and academic stability in this relentless march of educational standard and a globally interconnected student and education base, it is imperative to understand the practices and techniques currently employed to the analysis of student data to gauge their performance and ability. However, the analysis of this massive amount of multi-faceted data in an intuitive and insightful manner, still largely remains a matter of much divergence and complexity. Examining a few international benchmark practices such as the General Learning Outcome Dashboard developed by TMCC[1] displaying a high level view of enrollments, degrees, retention and credits,

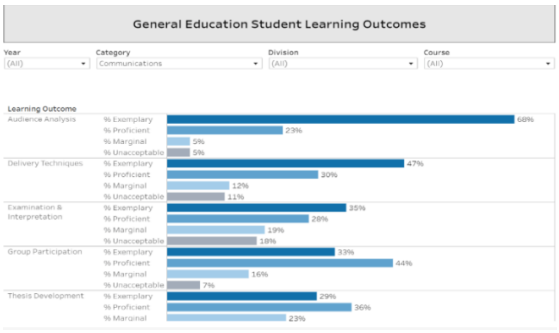

Fig 1. General Learning Outcome Dashboard TMCC [1]

or the Degree Completion Dashboard exhibited in [2] showing a comprehensive look into the general performance within the Stony Brook University at various levels over time, we can garner much insight on

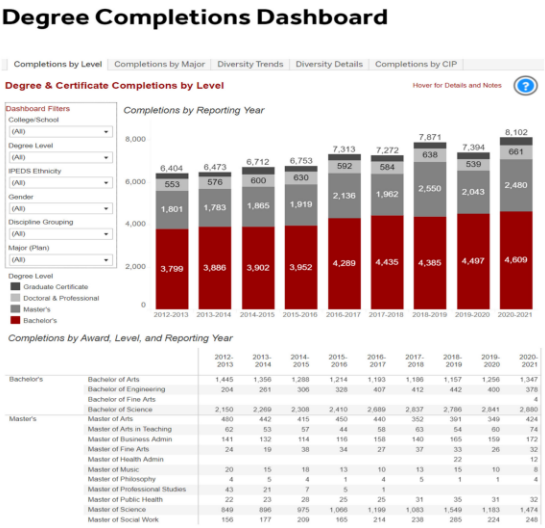

Fig.2. Degree Completion Dashboard in [2]

An organizational level, but to achieve our aim of student performance betterment, we must delve to a deeper granularity level. [3] Does this extremely well with a focus on integrating data from various sources and implementing a multi-dimensional analysis approach and a simple UI to improve teaching, program effectiveness and further strengthen the students' understanding of the learning outcomes. especially with the factors analyzed Nano, Micro, Meso and Macro levels as shown in the below figure exhibiting the analytical levels of the study.

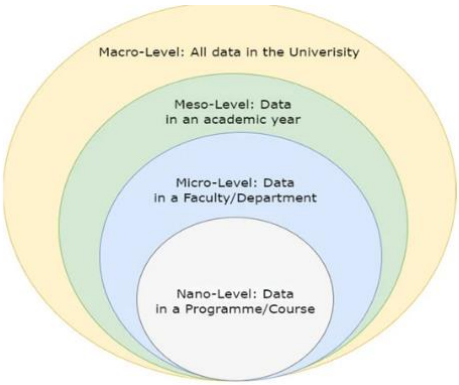

Fig 3. Levels of Analysis from [3]

The visualization strategies used in [4] enable more in-depth data exploration, facilitate quicker and better comprehension and help identify trends, anomalies and performance gaps. The use of Risk Quadrants to identify overall academic status and at-risk students, Interactive Scatter plots to identify clusters, patterns and examine the relationship of various factors with student performance, and Win-Loss charts that compare the learner's performance to their peers and allows tracking of individual progress made over time, make the research conducted in [4] a solid foundation for student performance analytics and even paves the way for the use of predictive models to pre-empt any possible difficulties and challenges that may arrive in the learning process - based on past data, observations and patterns - and preventive measures can be taken to avoid these or instructions and course flow could be altered for better student understanding and eventually, improved performance over time.

Fig 4. Win-Loss Chart showing Comparison from [4]

Furthermore, [5] explored the impact of various degrees of visualization techniques and how constant observation of evolution of student performances through simple but key and insightful visuals can vastly improve decision-making in educational institutions and make an impact at an individual student level. Thorough observation of the core course visuals over time, reveal various scenarios and changes in students' academic performances, providing clear classification, the ability to compare performances across cohorts, better temporal understanding of student data and identification of repeating patterns. Besides, it also aids in critical reflection on the inherent challenges and difficulties in the education system and allows for early intervention to support at-risk students and prevent future declines in performance. [6] Discusses principles and practices to be employed for designing academic visuals. It emphasizes the importance of providing identical views of different report presentations and the principle of offering multi-dimensional views of reports. [6] Also outlines 3 ways in which visualizations may help individuals reach their goals - activating the subconscious mind, focusing the brain and attracting opportunities, with focus on statistical indicators, measurements and user perceptions.

In the field of student performance analysis, various systems and technologies have been explored to enhance the assessment of students' academic progress and provide insights for improvement. One notable approach is the use of "Performance Analysis System for Student Academic Data."[7]. This system leverages HTML, CSS, JavaScript, and Bootstrap to create an application for students and teachers. However, it lacks technical specifics regarding the algorithms used for analysis, raises security concerns by not detailing measures to protect sensitive student data, and does not address data accuracy or system scalability.

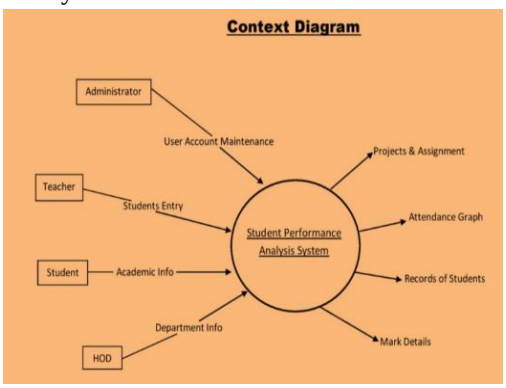

Fig 5.. Context Diagram for Overall System from [7]

As the context diagram[7] showcases, the system lacks the use of well defined parameters other than just

academic based parameters, like attendance or marks. There are many more parameters which can help determine a student's performance and their growth.

"Student Performance Analysis System using Data Mining" [8] emphasizes data mining and classification algorithms to analyze student data. However, it lacks the necessary technical details for a comprehensive evaluation, and like other systems, suffers from data privacy and security concerns.

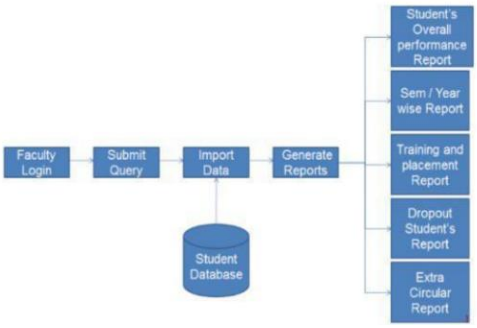

Fig 6. System Block Diagram. Adapted from [8]

Here, Usability, user training, data accuracy, and scalability are also areas that remain unaddressed.

"Education 5.0: Requirements, Enabling Technologies, and Future Directions" [9] explores the integration of advanced technologies in education, fostering critical thinking, creativity, and problem-solving skills. The concept focuses on creating a better paradigm, not specific to any technology. It focuses on the next iteration in the field of education and learning.

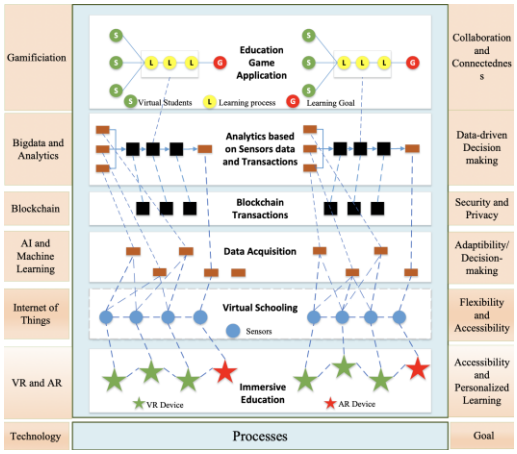

Fig 7. Two-way Stack Of Education 5.0. Adapted from [9].

However, the heavy use of technology Fig 7.[9] may lead to a digital divide among users. The less equipped audience may not achieve the intended satisfaction as the paradigm aims to deliver. Since a majority of this system is supposed to run wirelessly / over the cloud, ensuring the quality of online content and assessments becomes crucial.

Another system, known as "Student Performance Analysis System (SPAS),"[10] focuses on assessing students' readiness for placement using intelligent learning algorithms and a rich database. Despite its promise, it lacks transparency regarding the specific algorithms used and their complexity, does not encompass a broad range of performance parameters, and overlooks data validation and privacy concerns. Furthermore, it fails to address the interpretability of its predictions and provide information about the required resources for implementation.

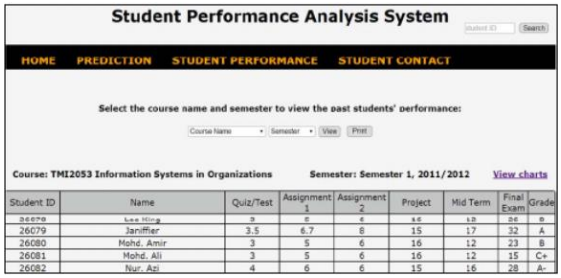

Fig 8. Student's Results Prediction Interface. Adapted from [10]

Similar to one of the most common issues found in the study, even SPAS [10] lacks the usage of well defined parameters and takes only the student's marks in account.

All of the aforementioned studies have largely highlighted the benefits of effective visualization techniques and the incorporation of personalized learning methodologies.[3] Advocates for a multidimensional analysis system for student data with a simple, interactive graphical user interface, consolidating a wide range of relevant data to improve teaching and learning quality and result in enhanced performance. [4] Facilitates in-depth data exploration, quicker understanding and comprehension, makes room for comparative analysis and makes it easier to communicate findings and trends to stakeholders; meanwhile [5] gives clear classification of student performance data, a better temporal understanding of the flow of student performances and allows for critical reflection on existing procedures and practices in the education system, allowing for improved instructions and early detection and prevention of possible difficulties and obstacles in the learning process. However, despite their valuable insights and possible lack of attention to other avenues, these

studies may have certain limitations or areas where they fall short. To mention few:

1.[3] Focuses on the implementation of the previously mentioned solutions to specific universities which may limit the adaptability and generalizability of the solution.

2. The visualizations put forth by [4] may lead to oversimplification of complex data points leading to superficial insights; visualizations such as the Sociogram may present too much data at once, the Win-Loss chart limits contextual information by comparing performance to peers while omitting external factors. The visualizations also lack customizability and certain visuals like the Scatter plot need a certain level of data literacy to be interpreted correctly.

3.[5] Also portrays similar issues with limited context behind performance classifications, static representation at specific time-points, lack of individual level indicators due to focus on group level analytics and finally, lack of actionable insights or recommendations for teachers to intervene and support students accordingly.

Considering these limitations, this study aims to bridge the gap by providing more intuitive and insightful visuals, with customisation possibilities and recommendations. Besides, our focus is also on providing a top-down view of the data allowing the user to choose their preferred level of granularity, along with ample consideration for external factors beyond surface level academic metrics and inclusion of a user-friendly UI and generalisable results. Hence offering actionable solutions to enhance instructions and practices in educational institutions, leading to improved student performance.

4. [7] lacks the usage of various important parameters other than academics to assess a student. In addition to this, it lacks security and accuracy too. [8] and [10] have similar limitations as well, where [8] lacks scalability, accuracy and security while [10] lacks the usage of proper parameters other than just marks and attendance.

5. The technology used in [9] is very advanced resulting in division among users who can take an advantage of these technologies and the less equipped users who may not get what is aimed to be delivered to them.

In conclusion, our literature survey shows how one can use effective visualization techniques and tailored learning methods for each student to improve teaching processes and enhance the learning quality. Past studies suggest the use of multidimensional analysis systems with user friendly interfaces. However, these studies also reveal certain limitations such as oversimplification of data, focusing too narrowly and lack of contextual depth. Our study aims to solve these issues by creating and using easy-to-understand visuals, customization options, actionable insights which all come together to help improve how education is done and enhance the student performance.

III. METHODOLOGY

This study takes a combination of observational, quantitative and qualitative approaches to analyzing student performance data. The data is collected through various channels - university records of attendance, academic performance metrics like marks and CGPA, both students' estimation and teachers' feedback about key personality traits in students and level of technical and soft-skills. The data observed and recorded over a specific time period, is standardized for analysis, and the data collection methodologies are designed to give both, a quantitative as well as a qualitative viewpoint of the data, enabling a holistic analysis and a deeper understanding of key student performance factors, possible obstacles for the respective paths that a student may choose, potential areas of weakness, magnitude of proficiency in strong areas along with institutional shortcomings and scope for improvement through a study of the historical data. Visualization techniques are explored in this study, utilizing data from the records, observations and feedback batch of Engineering students and the respective department professors. To understand the scope and possible affecting factors, initially, all involved professors were personally interviewed regarding their procedure of profiling, grading and evaluating student performance and deriving insights from them. Then, data was gathered from university records of students' marks, attendance, academic involvement, soft skill estimations, etc; followed by both self and professor graded evaluation of technical and soft skills of students through Individual responses in digital forms, along with their recent history of co-curricular and extra-curricular involvement. One of the points of

reference for this study has been leland Wilkinson's Grammar of Graphics which gives a systematic framework towards building customized statistical visualizations by studying the raw data, applying demographic detail and context, understanding how to effectively combine data points with geometric objects - bars, lines, plots - and visual properties such as color, shape, size and position. Statistical transformations allow for data summarization and aggregation before or in line with data visualizations and applying GoG principles leads to customized, intuitive and insightful visualizations that are tailored to specific educational analytics requirements and to answer specific questions as per learners' demographics.

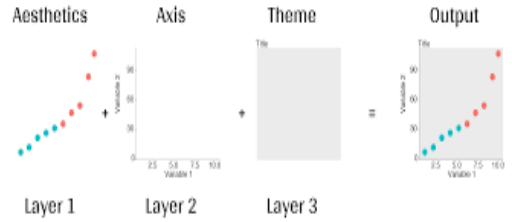

Fig 9. Building a visual using Grammar of Graphics principles.

Data Type	Visualisations
Numerical	Histograms, Box Plots
Categorical	Bar Charts, Pie Charts
Time-Series	Line Charts, Area Charts
Multivariate	Scatter Plots, Heatmaps
Geospatial	Choropleth Maps, Bubble Maps
Textual	Word Clouds, Topic Models

Table 1. Summary of Data Visualisations used with different data formats according to principles of GoG.

Additionally, Temporal Visualization techniques used, visualize the changes in student performance over time, which help identify trends, seasonality, long-term patterns in student performance data, factors affecting student performance at critical points of time in a year and explore potential solutions to recurring problems. These visualizations generally include Time-Series charts, Line-Charts, etc to track academic progress, exam scores and attendance patterns over the course of time.

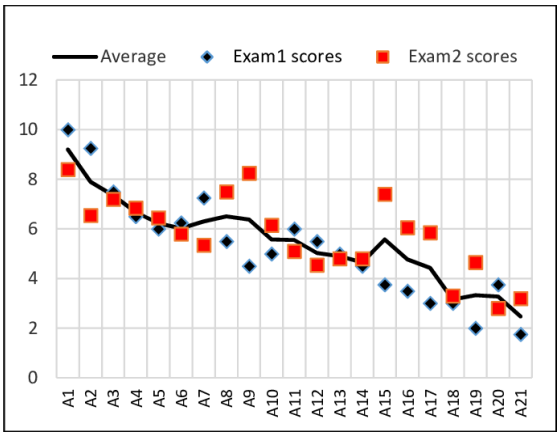

Fig 10. Illustration of Temporal Visualization in assessing exam scores [Source: ResearchGate]

A culmination of all design & analysis strategies, visualization methodologies and practices results in Dashboards that provide a comprehensive view of student performance data and allow users to interactively explore data using slicers, filters, tooltips, drill-up and drill-down capabilities, for a more insightful and engaging experience. Dashboards aggregate and interactively present easy to interpret visualizations about exams, grades, attendance, behavioral data, soft and technical skill sets and their respective proficiencies among the students, hence allowing for an all-round, holistic view of the students' learning and performance.

To gather data for our study, the data collection process involved taking surveys of the faculty members within our college. Through these surveys, our aim was to find out what parameters are employed by the teachers other than traditional metrics which are marks and attendance, while they evaluate a student's performance. We made sure that the information was collected from both teachers and students. We followed ethical guidelines throughout this process and maintained the integrity and confidentiality of the responses gathered by us.

Following our data collection, we systematically stored the gathered data in a MongoDB database. MongoDB was chosen due to its flexibility, adaptability and compatibility with both our backend visualization tools and the frontend user interface. By using MongoDB our aim was to take advantage of the adaptability of the document oriented databases to accommodate a wide range of data sources and also maintain strong and efficient connectivity with the

backend and frontend. The increase in efficiency of data management and retrieval processes was noticeable after choosing MongoDB as the database.

Based on the survey conducted to ask the faculty about the parameters they use to assess a student's performance, it was decided that we will focus on assessing the student traits using the OCEAN framework. This would help the teachers assess students on parameters other than just academics. OCEAN framework helps understand how open-minded, conscientious, extrovert, agreeable and neurotic a student is. This information shout each student was gathered by a questionnaire which was answered by a teacher for the student and also the student to self-report their own traits.

Using both these gathered information, we can have a more nuanced analysis of a student's performance and traits.

In our study, we then designed and created four unique dashboards to visualize the gathered data, each meant to serve a unique purpose. The main dashboard provides an overall holistic view of a student's progress and the areas which require improvements. It displays all the important information for both the teachers to easily understand how well a student is performing and where should the teacher focus more on for their improvement and the student to see their performance and where they can work on to improve.

The attendance dashboard is designed to display monthly subject-wise attendance for each student. The teacher simply has to select which student's data they want to view and the visuals related to that student's attendance will be displayed for them to assess the student. Intuitive color-coded indicators are used to display the student's attendance for teachers to quickly assess student's attendance status. Attendance trends over time can easily be identified by the line graphs used for each subject's attendance, enabling the teachers to take actions to address any attendance issues a student might have.

The next dashboard is designed to display marks for each student. It works in a similar way as the attendance dashboard does. It displays subject wise marks throughout a semester for each student. It uses the same intuitive color-coded indicators for teachers to understand in which subject a student is lacking and requires some more attention to improve.

Lastly, the final dashboard displays the student's personality traits. Here, the data from the OCEAN questionnaires which were answered by both the teacher (For each student) and the students for themselves are displayed. A radar chart is used to compare students' self-perception and the assessment given for them by their teachers. Teachers can then view the OCEAN traits characteristics for each student, this helps them to tailor the learning experience for each student to improve their personality and traits.

By designing the above dashboards, our aim was to provide the educators with useful tools for making better data-driven decisions. This would enable them to carefully monitor a student's progress, identify their weak areas and then tailor personalized learning experiences for each student to improve their performance.

Initially designed and developed for the final year students for our branch in our university, our application had a goal to make the assessment process easier for both the students and their faculty. Throughout the development process, we received regular feedback from the faculty and the students to improve our application for better usability. Using this iterative approach, we could continuously improve our application and we made sure that our application provided an effective and useful tool for monitoring and assessment of student performance.

IV. RESULTS

The end product of the efforts undertaken to understand and analyze student performance data in a deeper, more intuitive way were the actionable insights that we were able to garner from our interactive and informative dashboards. Having carefully considered the use of different techniques to get the most useful information from the data available through the visuals, we were able to get important insights and interpretable information that can yield actual results.

The following table summarizes all the visualizations used in our application, along with their parameters and description. Using a wide range of visualizations allows us to provide a comprehensive understanding of student performance and hence make the data-driven decision-making process easier.

Visualization	Parameter represented	Description
Slicers	Student selection	Choose and slice the dimension for analysis.
Bar chart for attendance	Overall Attendance	Displays overall attendance for all the subjects together.
Donut chart	Absence % Vs Attendance %	Displays the student attendance and absence percentages.
Data Card for Attendance	Attendance %	A color coded card showing the overall attendance.
Line charts for marks	Cumulative attendance	Tracks the cumulative attendance for a subject per lecture.
Bar chart for marks	Overall Marks	Displays overall marks for all the subjects together.
Line charts for marks	Test-wise marks	Displays the test wise marks for each subject.
Data card for marks	Overall Marks %	Uses a colour coded card to display the overall marks percentage.
Radar chart	OCEAN Traits	Visualize and compare student personality traits.

Table 2. Summary of visualization techniques used for Student Performance Analysis.

The main Overview dashboard consists of a slicer bar where users can slice across time - batches over years, gender, departments and even on an individual level of granularity. The cards atop the report show surface level metrics like students with highest marks, attendance and co-curricular performance, The top ribbon also shows the distribution of student count by Gender. The Overview report charts include - a bar chart to show attendance numbers for the batch, along with a pie chart for mean marks across the batch over time, a stacked bar chart to show the progress of OCEAN traits,and a ribbon chart to show student progression and effort dedicated to co-curricular activities like competitions and certifications. All these visuals include flexible filtering options like Top N filtering, specific filters and also cross filtering among charts themselves.

Fig 11. Main Dashboard.

Below is a snip of the questionnaire we floated to teachers to get their perception of student traits and profile students as per the relative extents of their personality traits, which helps assess student personality types, learning preferences and methodologies.

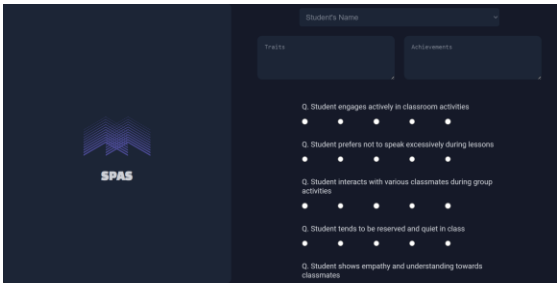

Fig 12. Questionnaire for OCEAN Traits upon logging into our application.

The following is a snip of the UI of the application developed by integrating all reports generated to give a comprehensive view of surface level academic metrics such as marks, attendance - variation over time and aggregations; along with personality metrics in the radar chart and other visualizations that cover all aspects of student learning and progress.

Fig 13. Application view.

V. CONCLUSION

Our research shows the importance and advantages of using effective data visualization techniques in the analysis of multidimensional student performance data. By designing and creating new and effective ways to display all the important information, we provide educators with powerful tools that help them to make data-driven decisions and tailor personalized learning experiences for students. Throughout our research, we try to showcase the importance of using parameters beyond just marks and attendance while evaluating a student's performance. By using OCEAN traits assessments, extra curricular activities, attendance and marks records, educators can gain effective insights of a student's performance, their strengths, weaknesses and needs.

The iterative development process that we used helped us continuously improve our application based on user feedback. This resulted in making our application more user friendly and providing educators the functionalities they asked for. It is however important to understand that our study has its limitations. This includes the scope of the data collected and the specific context of our study population. It is important for future studies to investigate the scalability and generalizability of our findings across a diverse educational context and student population.

Looking forward, it is important that we keep updating our study with new ideas to improve the visualization of educational data in order to do a more effective analysis of it, leading to better data-driven decision making. It will then be easier for the educators to understand how well a student is performing and make decisions to help them improve and succeed. Overall, our study shows that using the educational data in this manner can change the traditional teaching techniques, making education more focused on helping each individual; student do their best.

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