Application of Network Models to Assist in Data Science Curriculum Using Program and Course Learning Outcomes

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Abstract

Creating a robust curriculum is key to ensuring success in an academic degree. This paper provides insight into the use of data science tools to enhance curriculum mapping in higher education. Using course learning outcomes and program (degree) learning outcomes, a network map is produced to ensure synthesized outcomes that can allow for great success of a program and enforce student education. Based off this project, different departments and universities can obtain insightful information about their own curriculum and how successful their curriculum mapping is. Students can also benefit from seeing the way course learning outcomes map to their program learning outcomes which could guide them through their studies and future careers.

Keywords

Curriculum Analysis, Data Science, Network Modeling, Educational Mapping, Learning Outcomes

1. Introduction

Higher education curriculum development is always changing. Universities are faced with new courses, new ways of teaching, and new technologies that only make maintaining a successful curriculum nearly impossible without evaluating how courses map to the overall program objectives. Students are always trying to stay on track to finish their degrees and maintain knowledge of new technologies, so they can succeed in their future careers. Students rarely have any idea of what is expected of them in a course until they get to the end of the course and take a final exam. By having an interactive tool that maps specific details about a course and how it relates to the overall program learning outcomes (PLO's), it would allow faculty and students to learn more about the degree program and get insight on specific details. Faculty can ensure that courses cover all objectives and outcomes needed for a successful degree. When creating a course, faculty also can see if course learning outcomes are mapped to program learning outcomes and is not just a filler course that does not entail content that relates to the overall degree. Visualizing the way the content of a course, in any given degree program, is being mapped to their course learning outcomes (CLO's), faculty and students can get a better understanding of the course and can ensure greater knowledge of the contents discussed in the course. This would also allow students to familiarize themselves with topics and can see how these course learning outcomes can help them in the future.

This paper presents the concept of using a network modeling tool with text data from the undergraduate Data Science (DS) curriculum at Florida Polytechnic University as a use case. The DS Curriculum ensures that students, the future data scientists, develop mathematical models, computational methods and tools for exploring, analyzing and making predictions from data. That they ask appropriate questions about data and interpret the predictions based on their expertise of the subject domain (Florida Poly Degree Program: Bachelor of Science, Data Science). With wanting to ensure great success for students, mapping the specific course learning outcomes of each core course in the DS program to the program learning outcomes of the entire DS program helps visualize how each course has an impact on the degree being achieved and can allow for great student success. For the analysis considered in this work, the newly developed ABET learning outcomes for Data Science were used (Criteria for Accrediting Computing Programs, 2021-2022). They are as follows:

1. Analyze a complex computing problem and to apply principles of computing and other relevant disciplines to identify solutions.
2. Design, implement, and evaluate a computing-based solution to meet a given set of computing requirements in the context of the program's discipline.
3. Communicate effectively in a variety of professional contexts.

4. Recognize professional responsibilities and make informed judgments in computing practice based on legal and ethical principles.
5. Function effectively as a member or leader of a team engaged in activities appropriate to the program's discipline.
6. Apply theory, techniques, and tools throughout the data science lifecycle and employ the resulting knowledge to satisfy stakeholders' needs.

This last outcome summarizes what a truly successful undergraduate student in DS is able to achieve in industry and future careers.

Bloom's Taxonomy level of each CLO are also looked at, making sure the course achieves what it is supposed to and at the correct Bloom level ensuring growth throughout the degree program. The final tool presented is ensuring that course content aligns with the course learning outcomes. To prove a successful course, a model syllabus is presented, containing all necessary information to model course learning outcomes to program learning outcomes with the correct Bloom's level and will show how the content of the course maps to the course learning outcomes without unnecessary filler information on a syllabus.

In this paper, a literature review of Bloom's Taxonomy, curriculum design, and how educational mapping works is provided. The next section will talk about the text data used and the data science tools used to create the mapping. The following section discusses what the network map looks like and the information it provides to students and faculty. A table is then created to show the mapping of course content to course learning outcomes. Finally, the last section draws conclusion from the tools being used and how this project could be updated in the future with some recommendations of how to improve the curriculum in the DS degree at Florida Polytechnic University. Throughout this paper and manual, Courier font will denote R packages, R code and column names.

2. Literature Review

2.1. Bloom's Taxonomy

Bloom's Taxonomy, which is the Taxonomy of Educational Objectives, is a tool created to classify the educational level of thinking, learning, and understanding in a hierarchical framework (Krathwohl, D. R.). The levels can be seen below in Figure 1. Benjamin Bloom believed that this tool could serve more than just as a measurement. He believed that this would be the basis of determining goals in a course and that it would allow for common language about goals between different types of people (Krathwohl, D. R. 2002). There are six categories that differentiate between cognitive skills and as you go up in this framework, you are reaching higher order thinking skills.

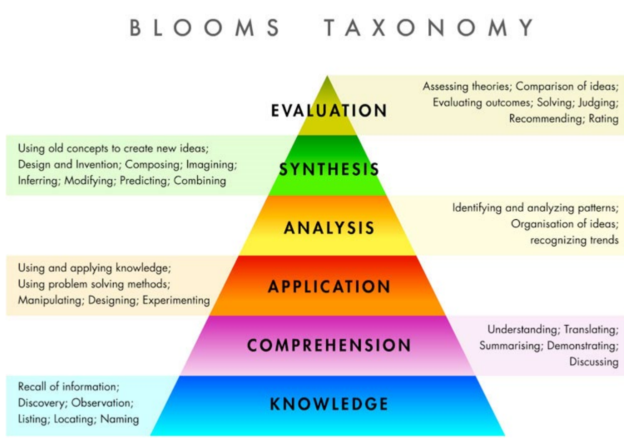

Figure 1. Example of Bloom's Taxonomy, 1956 in pyramid structure. Source: Alford et al., 2016

Benjamin Bloom determined that the lowest order of thinking skills is knowledge, then comprehension and application. The next higher order thinking skills are analysis, synthesis, and evaluation (Bloom, B. 1956). Each level should build on each other as the students pursue an education. By using these levels, students are pushed to develop a deeper understanding of the courses they are being taught. By using Bloom's taxonomy, faculty are encouraged to create course learning outcomes using verbs that would allow students to see what they can do as a result of the learning outcome. This would also allow students and faculty to get a deeper understanding of how courses of higher level (senior-level courses), should achieve higher levels of cognitive skills, and would lead to deeper learning and evaluating.

2.2. Curriculum design/analysis

Curriculum design is a key feature of creating a successful degree program. "Curriculum design focuses on the creation of the overall course blueprint, mapping content to learning objectives, including how to develop a course outline and build the course. Each learning objective is met with assessment strategies, exercises, content, subject matter analysis, and interactive activities" (Wellesley College – Curriculum Design Resources) Courses need to flow in a certain order and need to reach certain Bloom Levels for higher level courses. Different factors need to be taken into account with the design of a program. Faculty want to ensure students are successful and able to apply their studies in the future. They can avoid overlap in courses, or replication of contents (Dawson, S., & Hubball, H. 2014). This will also allow students to feel like every course in their degree program is important and relevant in its own way.

Continuous curriculum improvement is a good tool for faculty to ensure successful curricula in their degree. Assessment is a vital component to educational planning and teaching because it is a way to gather accurate evidence of student learning and information to inform instructional decisions (Kelting-gibson, L. 2012). By assessing and analyzing curriculum, it can visually help faculty and students see the outline of the degree and goals needed to achieve in order to succeed. Students do not usually understand why courses are offered in a specific order. They are usually given a guideline and told to follow it. By getting a deeper understanding of the design of a curriculum, students will have the advantage of understanding more about their curriculum and degree. This would allow students to truly decide if the degree program they are pursuing is the right one for them and fits the path they want to go on.

With data science emerging, new skills need to be taught. Fast technology change and new skills demand requires re-thinking and re-designing both traditional educational models and existing courses to reflect multidisciplinary nature of Data Science and its application domains (Demchenko, et al. 2019). Taking a deeper look into the design of curriculum, ensuring that new topics are being taught, is of the utmost importance to have successful students who can lead in the data science world. This mapping tool can allow faculty to analyze their curriculum in place and can help determine if outcomes need to be changed or updated.

2.3. Educational Mapping

Since curriculum design contains so many aspects, it is important to be able to map the relationship between different variables in a degree. Mapping these variables can help identify overlaps or gaps in a curriculum plan. It can also help identify the path a student needs to take and can show learning levels and outcomes in a way that is easy to understand. Typically, with educational mapping, the mapping is done in a table setting, where different courses are listed in rows and the attributes of that course are listed in columns. This is a very flattened way to see the way a curriculum is set up. By creating a network model connected with the educational data, the user can see many details about the curriculum and course and can visualize and understand the curriculum better (Willcox, K. E., & Huang, L. 2017). Faculty can use these maps to validate their intended learning outcomes and associated content of their courses (McDaniel et al. 2005).

By using in conclusion by using Bloom's taxonomy in curriculum design will help students to see and understand how course goals and objectives are achieved. Faculty can view the general mapping of the courses being taught, ensuring that the curriculum provides a comprehensive overview of the learning outcomes while minimizing repeated material. Faculty would also be able to create syllabi that encompass correct information about the course and topics that relate to one another and that map to course learning outcomes that eventually map to program learning outcomes at an appropriate Bloom's Taxonomy level.

3. Research Methodology

This project starts with a collection of course information from the Department of Data Science and Business Analytics (DSBA) at Florida Polytechnic University. A network model is created to map courses accordingly. The network model is designed to represent different objects and their relationships. Unlike a hierarchy, network models can have more than one relationship with different objects and can be viewed as a graph where object types are nodes and relationship types are arcs. In this case, the network model would first need to be able to read data of the degree being explored. Each course would need to have a relationship which would include addresses and leads-to. This would allow the network model to map correctly. Other information that would be needed is course learning outcomes, program learning outcomes, topics taught in each course and a course description. With this information, a network model is created to allow users to be able to use this tool to help understand what topics they will be learning and how it relates to the overall program.

To have the network model run correctly, the data needs to be organized in a very specific way. An Excel sheet is provided to use for the data. The step-by-step guide of how to write the data can be provided upon request. Following the guidelines will ensure that there are no issues when applying this tool to a different department. Text mining and

analysis tools were used throughout the project to allow this tool to work correctly. The text analysis allows for the mapping functionality to work as well as for the table outputting to show the text being analyzed. Mapping of all parts of the courses is crucial to a readable and functional network model. One of the most important parts to map are course learning outcomes to program learning outcomes. The creation of the CLO is very important for every course. There needs to be a relationship between the topics being taught in the course and the CLO's. This then leads to mapping the course learning outcomes to the program learning outcomes. At Florida Polytechnic University, each degree program has its own PLO's. These outcomes consist of topics for which a graduate should have exceptional knowledge. Being able to visualize the mapping of CLO's to PLO's can give greater insight into the success of a degree program in terms of curriculum design.
In Figure 2 below, there is a general curriculum network mapping and then a concrete example from the curriculum at Florida Polytechnic University. Improving this mapping will give insight to information that is not readily available to all students. Students will get a better understanding of their courses, and faculty will get a better understanding of the program that they are offering and can assist them to correct anything such as objectives and outcomes.

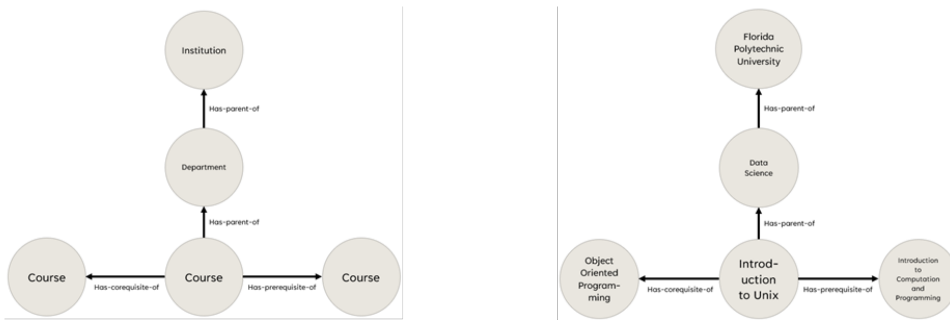

Figure 2. Curriculum network mapping example

4. Results and Discussion

4.1. Dashboard

Each of these tools and visualizations, aiding in the assessment of a degree program, are outputted into a `flexdashboard`. `Flexdashboard` is a format for converting an R Markdown document to a grid oriented dashboard. The dashboard flexibly adapts the size of its components to the containing web page (CRAN 2020). This allows for a user to easily go through the outcomes and findings and see if courses need further evaluation. The dashboard is formatted in a way that is easily understandable and accessible for any user. The output of the dashboard is simply a .html file which allows anyone with the .html link to access it and see the tool being applied. The `flexdashboard` has six tabs, corresponding to many of the visualizations and tables that give users information about a degree program. Figure 3 shows the screenshot of each of the tabs on the `flexdashboard`.

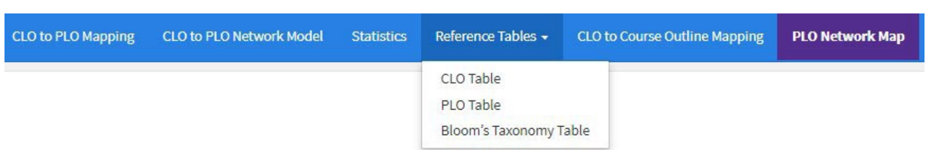

Figure 3. Dashboard Tabs from the flexdashboard created

4.2. CLO to PLO Mapping

A model is produced to show the mapping of Course Learning Outcomes to Program Learning Outcomes. Each course in the data science curriculum has between three and six course learning outcomes, each unique to the course being taught. The Data Science department has six program learning outcomes, that when completing the degree plan, should know and be able to do. The CLO's are labeled one through six and the PLO's are labeled A through F. Labels were done like this to be able to differentiate between the two types of outcomes without causing any confusion. More about the way the data is formatted can be provided upon request. By looking at 18 core courses in the program, there was a total of 85 different course learning outcomes. An interactive visualization was then created. Each PLO was assigned a color, and if a CLO mapped to it, then the color was highlighted. If there was a CLO that was assigned to multiple PLO's, then as you click through the different PLO's, the color would change respectively based on that PLO. Each line in the visualization is a different course with its respective number of CLO's. If one hovers over a CLO, one will get the description of that CLO with its Bloom's Taxonomy Level. Figure 4 below has all the PLO's selected and shows what the model looks like.

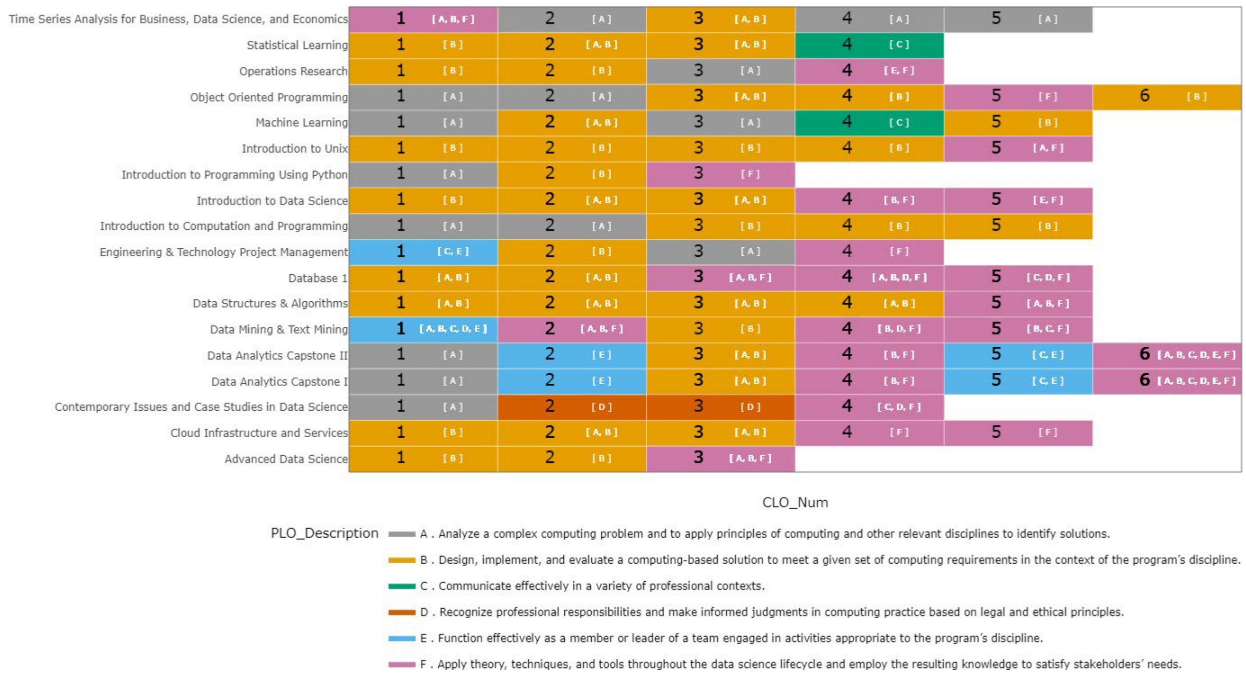

Figure 4. CLO to PLO Mapping

4.3. CLO to PLO Network Model

Another visualization tool was created to accomplish this as well. A network diagram starts with the initial node named Courses. When clicking that node, 18 additional nodes appear, each representing a different course in the department being evaluated. A user can click on any of the course nodes and an additional number of nodes will pop out. The next set of nodes represents each CLO in that respective course and if you click a CLO, a new node will appear which actually tells the user the description of the CLO and ends off with a bracket of the PLO('s) that CLO maps to. This network diagram allows for users to see the hierarchy and relationships between the different variables in a program. Figure 5 below shows the sample output for the Introduction to Data Science course. Once clicking the course names, five new nodes appear corresponding to the five course learning outcomes and when the user clicks those nodes, new nodes appear with the description of the course learning outcome and the PLO that CLO maps to.

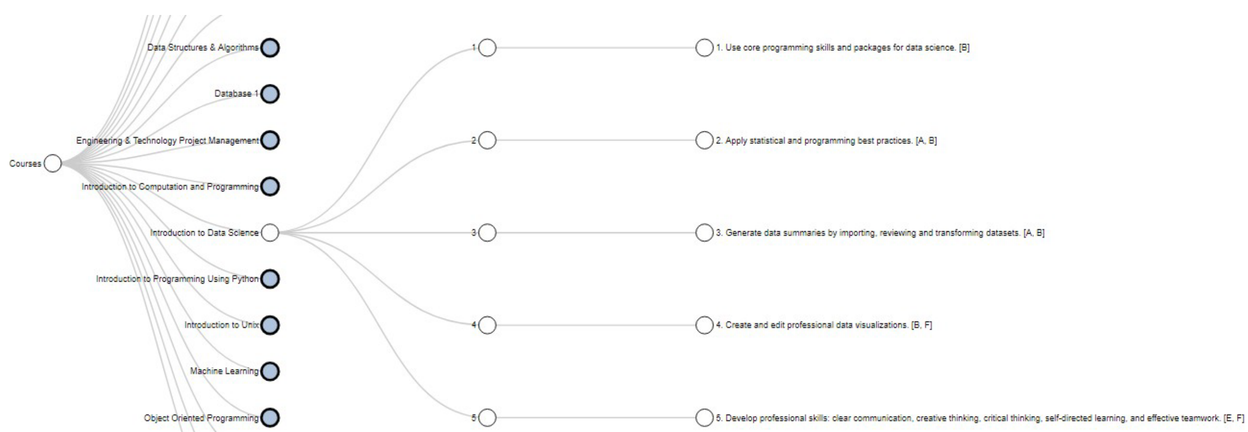

Figure 5. CLO to PLO Network Model, Outputting only one of the courses in the data - Intro to Data Science

4.4. PLO Network Map

Another network model is created to visualize similar information in a different way. This second network map starts with the initial node called PLO. Once clicked, six additional nodes appear, representing the six PLO's in the degree program being assessed. When the user clicks on any of the PLO nodes, multiple nodes will appear, representing the course names that map to that PLO in one (or more) of its course learning outcomes. Clicking on the course name node will allow the user to see which CLO is mapped to the PLO in each course and if a CLO has a Bloom's Taxonomy word, then a new node will appear with the word used to evaluate the level of that CLO. In Figure 6, a sample of the PLO Network model is shown using the Introduction to Data Science course. The first PLO (A) was clicked and then Introduction to DS course and in this figure, two of the CLO's are shown with their respective Bloom's Taxonomy word.

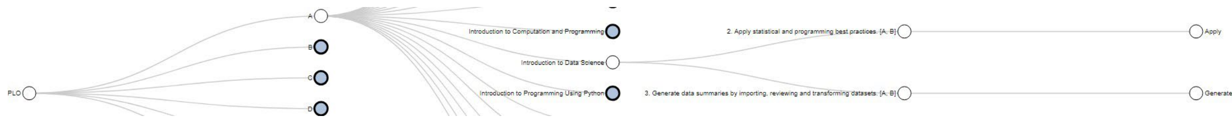

Figure 6. PLO Network Model, Outputting only one of the PLO's in the data – PLO A with two sample CLO's from Intro to Data Science course

4.5. Statistics

In this tab, different statistics are outputted based on the data inputted and pulled. The first table on the page simply outputs the course names and how many course learning outcomes each course has. This is useful to keep track of the amount of CLO's in each course. Although there is no limit for the amount of course learning outcomes, an ideal course should not have so many and would still be able to capture all the outcomes when completing the course. The table is sortable by name of course or by the count of CLO's.

On the top, second column of the page is a table showing the PLO Statistics for program learning outcomes in the Data Science Department. This table provides insight into the general breakdown of how many different course learning outcomes map to a specific PLO. Although there was a total of 85 different CLO's, some CLO's map to multiple PLO's and that is why there is more than 85 CLO's throughout each PLO.

On the bottom, second column of the page is a table showing which Bloom words were pulled from the CLO's and used and the total count for each word. Out of the 85 course learning outcomes, 20 of them did not have a Bloom word specified. The main Bloom levels used were demonstrate, identify, explain, and describe which come from the Comprehension and Application thinking levels. Table 1 shows the top 10 words used out of a total of 28 different Bloom words throughout the degree program.

Table 1. Top 10 Common Bloom Words used in DS Program

Bloom	Bloom Word Count ↓
Demonstrate	16
Identify	12
Explain	9
Describe	9
Apply	8
Analyze	8
Develop	4
Complete	4
Use	3

4.6. Reference Tables

4.6.1. CLO Table

Before the modeling portion of this project, it is important to ensure that all course content is readily available. A big part is ensuring that each course learning outcome has its respective Bloom's Taxonomy word. Using data science and text mining tools, CLO's were read and the Bloom word associated with that CLO was pulled out. A sample output is provided in Table 2 below using the Introduction to Data Science course. In the last column of the table, the Bloom word is outputted. This allows faculty to get an idea of the thinking level for the specific CLO and can give a general idea of the overall thinking level for the course. Higher-level courses should have higher Bloom levels, so being able to see each Bloom level on its own and get a whole picture of which words are being used will assist in ensuring that this is true. This can also give general insight into which Bloom words are most commonly used overall in the core courses in a department and see if there is any pattern. This reference table also allows for filtering so whether a user wants to filter for a specific term in a learning outcome or a specific bloom word or just look at the CLO's that are missing a Bloom word, this is a useful table to reference.

Table 2. Reference Table - Course Information with Bloom Words, Filtering just for Intro to Data Science Course

Course Name	CLO	CLO Description	Bloom
introduction to data sc			
Introduction to Data Science	CLO1	1. Use core programming skills and packages for data science. [B]	Use
Introduction to Data Science	CLO2	2. Apply statistical and programming best practices. [A, B]	Apply
Introduction to Data Science	CLO3	3. Generate data summaries by importing, reviewing and transforming datasets. [A, B]	Generate
Introduction to Data Science	CLO4	4. Create and edit professional data visualizations. [B, F]	Create
Introduction to Data Science	CLO5	5. Develop professional skills: clear communication, creative thinking, critical thinking, self-directed learning, and effective teamwork. [E, F]	Develop

4.6.2. PLO Table

The second table in the Reference Tables tab is the PLO table. This table lists the letter corresponding to the program learning outcome and then the description of the PLO. If a user is unsure about which PLO the letter is referring to, the user can go back to this table to use as reference.

4.6.3. Bloom's Taxonomy Table

The final table in the Reference Tables tab is the Bloom Taxonomy Table. These are the words from Benjamin Bloom and others in *Taxonomy of Educational Objectives* in 1956. This ideally should stay the same for any department and can be used as reference when looking at the different options for Bloom Words.

4.7. CLO to Course Outline Mapping

The final variable being evaluated is the way course learning outcomes map to the course outline which is essentially the material being taught in the course. This was done by grouping each CLO for a course together and pulling out the words that appear both in the CLO descriptions and in the Course Outline. A table was then created that says the course name, the words that appeared in the CLO, and then bolds the word wherever it appears in the course outline. Visualizing this information in a table, allows faculty to see where course learning outcomes can be improved. Ideally, the content of a course is chosen and based on that information, the CLO can be created. This table would allow faculty to see, if maybe, that is not the case for some courses in the degree program. For students, this would also allow them to see what specific topics are important for them to know and understand and can ensure success in the course and in achieving their degree. Table 3 below, is a sample of the table for Introduction to Data Science course. The common words that appeared in both the CLO and course outline information are "core", "programming", "skills", "data", "science", and "effective".

Table 3. CLO to Course Outline Mapping, Outputting only one of the courses in the data - Intro to Data Science

Course Name	Words Matching CLO	Course Outline (pulled from syllabus)
Introduction to Data Science	core programming skills data science effective	overview of **data science** tools setup rstudio git github canvas resources using the command line version control introduction tracking project changes gitgithub exercises using markdown for documentation writing and rendering markdown documenting and sharing code foundational r **skills** introduction to **programming** with r defining vectors and lists working with functions understanding and interpreting **data** types of **data data** generation process working with **data** frames **data** wrangling **core** dplyr functions analyzing **data** frames by group joining dataframes tidy **data** principles reshaping **data** with tidyr summarizing sorting subsetting merging **data** introduction to **data** visualization the grammar of graphics and ggplot choosing **effective** graphical encodings exploratory **data** analysis introduction exploratory **data** analysis eda generating questions about **data** measuring variation exploring covariation checking missing values using **data** to answer questions case studies relational **data** and **data** import overview of relational databases working with dates and times working with factors exploratory **data** analysis exercise case studies exploratory **data** analysis eda exercise case studies model basics visualizing models model building web scraping and text **data** processing json **data** exploratory **data** analysis exercise final project work ethical responsibilities other **data science** tools case studies

4.8. Discussion

While working on this project, there were a couple of things that stood out. The first major one was that not all course learning outcomes had a Bloom’s Taxonomy Level for it. This means that there was no word that was found in the description of the CLO that matched with a Bloom Level and that it most likely needs to be worded better. By wording it better and using the Bloom words, faculty are providing a better opportunity for a student to understand what level they are at in terms of thinking skills. This also would allow for faculty to understand and ensure that lower-level courses and higher-level courses are being evaluated at the correct Bloom Level.

Additionally, applying this tool to a department gives lots of insight into the courses being offered. The flow of a degree program is key to ensuring success and that all starts with mapping different course variables to each other. Being able to visualize the mapping of CLOs and PLOs, allows faculty to really see how the courses in the program relate to each other at an overall level and provides students with an additional tool to get information about courses in their degree program.

5. Conclusion and Future Work

Throughout the project, the goal was to create a mapping tool to show the relationship between various variables in a course. Course learning outcomes were mapped to program learning outcomes with the respective Bloom’s Taxonomy Level. Each core course in the Data Science program at Florida Polytechnic University was mapped to a Program Learning Outcome. A table was then produced to show how course content (pulled from the syllabus) is mapped to course learning outcomes. This table shows that everything being taught in a course needs to have a purpose and if it does not have a purpose, then it needs to be updated.

In the future, this tool can be improved to allow more content to be output. Courses that do not necessarily have a Bloom’s Taxonomy word in the CLO, would output a Bloom word based on the information in the course learning outcome. This would allow for less manual input from faculty and can improve the way CLO’s are written and mapped.

When mapping course learning outcomes to course outline, some text mining tools were used to create more authentic results when pulling out matching words in the CLO and course outline. Although this did not change the entirety of the content of the course outline, certain words or numbers were dropped from the outline which might create some confusion with certain course outline descriptions. This could be further developed to incorporate a dictionary that would not change some words or remove only specific words, numbers, or patterns.

Incorporating a tool that would also analyze assessment data for the different CLO’s would be an additional feature that can be created in the future. This would allow faculty to have access to everything on one dashboard and can give complete insight to a course from start (CLO mapping) to finish (assessment). Assessment data would include items like students success rate or which CLO had the most successful assessment.

An additional tool that could be created based on this work would be to automate a syllabus that would include this mapping tool and include necessary information. Faculty would have access to this file and can simply click their course, and would be able to see the new syllabus created. This would allow for better insight for a student or faculty member and can create a uniform syllabus for all courses in a university. Some preliminary work has been done to start implementing this tool. In the two final tabs of the `flexdashboard`, there is a tab called “Example Syllabus (Prototype)” and “Future Implementation”. Ideally, the example syllabus tab is the format of the different tools being applied to what the possibility of a syllabus could look like. Each tool used in this project would be outputted based on the different course syllabus wanted to be produced. The Future Implementation tab allows for a user to click through the courses that are in the dataset and would be able to see the output of three of the tools created. The page changes as a different course is clicked on. The future implementation will also include any necessary course information. For example, if a course has a final project, the automatic syllabus creator would include the rubric for the project with any additional information needed.

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Biographies

Orel Yoshia is a student in the Master's program of Computer Science – Data Science track at Florida Polytechnic University. She received her Bachelor's degree in Computer Science - Information Assurance and Cybersecurity from Florida Polytechnic University. Her interests include institutional research, spatial and data analysis, text mining, and project management.

Dr. Reinaldo (Rei) Sanchez-Arias is an assistant chair and assistant professor in the Department of Data Science and Business Analytics at Florida Polytechnic University. His research interests include data mining and statistical learning, numerical optimization, operations research, and data science education. Sanchez-Arias received a Ph.D. in Computational Science from The University of Texas at El Paso, and a B.S in Mathematics from Universidad del Valle in Cali, Colombia. He is a member of SIAM, INFORMS and IEEE.

Dr. Shahram Taj joined Florida Polytechnic University in August 2016 as a professor of logistics and supply chain management. He served as the academic program coordinator of science and technology management and the academic program coordinator of graduate programs in 2017. Since January 2018, he has served as the chair of the department of data science and business analytics. Taj has extensive tenure in academia. He was professor and chair of the Department of Management and Marketing at Lawrence Technological University in Michigan from2013 to 2016. He served as The Cameron Endowed Chair of Management and Marketing at the University of St. Thomas in Houston from 2008 to 2013. Taj previously taught for more than 20 years at the University of Detroit Mercy. Taj has conducted more than 100 projects at Ford, Visteon, New Venture Gear (formerly joint venture of GM and DaimlerChrysler), GM-Holden, Baker Hughes, and Schlumberger in the United States, Germany, Australia, and Japan. The projects have covered productivity improvements, implementing lean manufacturing, and optimizing process design. In 1999, he earned the Franz Edelman Finalist Award for Achievement in Operations Research/Management Science for projects that resulted in $15.5 million capital savings and a profit increase of more than $2 billion for Ford Motor Company. Taj has served as thesis advisor/reader of more than 100 graduate students at the University of Detroit Mercy, including a doctoral thesis committee at MIT. He served as the track chair of the "Lean Manufacturing, Manufacturing Information Management, Supply Chain, and Product Development" for the SAE International in Ireland, Spain, and France. He has published 68 refereed articles in journals and proceedings of many international conferences. Recently, he published several articles on the adaptation of lean production in China, and most recently in areas of sustainability and business model innovation