Undergraduate Industrial Engineering Majors' Software Preferences for Solving Statistical Process Control and Operations Research Questions

Dr. Emre Tokgoz, Quinnipiac University

Emre Tokgoz is currently the Director and an Assistant Professor of Industrial Engineering at Quinnipiac University. He completed a Ph.D. in Mathematics and another Ph.D. in Industrial and Systems Engineering at the University of Oklahoma. His pedagogical research interest includes technology and calculus education of STEM majors. He worked on several IRB approved pedagogical studies to observe undergraduate and graduate mathematics and engineering students' calculus and technology knowledge since 2011. His other research interests include nonlinear optimization, financial engineering, facility allocation problem, vehicle routing problem, solar energy systems, machine learning, system design, network analysis, inventory systems, and Riemannian geometry.

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Emre Tokgöz

Emre.Tokgoz@qu.edu

Industrial Engineering, School of Engineering, Quinnipiac University, Hamden, CT, 06518

Various software packages can be used by engineering students to solve problems for Statistical Process Control (i.e. SPC) and Operations Research (i.e. OR) applications. These software packages require learning and implementing programming languages that help students to understand application insights of data visualization, statistical distributions, diagrams and charts, and regression and correlation analysis in SPC, and linear programming, integer programming, non-linear programming, Markov chains and linear algebra in OR. Instructors teaching OR or SPC courses can focus on a single software package or several software packages for teaching applications of various concepts in each one of these courses however students' computer programming preference could be different. The choice of software to be taught is important for ease of OR and SPC applications and how much students are comfortable using the corresponding software package. Students' software preference could change depending on the OR and SPC concepts covered, therefore extensive knowledge of software related to above mentioned concepts covered in OR and SPC courses strengthens users' knowledge and ability to make a software choice depending on the concept covered. In this work, qualitative and quantitative analysis of Industrial Engineering (IE) undergraduate students' software choices to solve various OR and SPC questions will be presented with their computer programming ranking for solving these questions as a part of the OR and SPC courses. The software packages compared by the students included Excel, SPSS and R for SPC, and Excel-Solver, Matlab and Lingo for OR.

Introduction

Software knowledge of Industrial Engineering undergraduate students is the gateway for finding solutions to complicated numerical problems. Some of the well-known software used in sub-disciplines of IE applications include (but not limited to) Excel, Lingo by Lindo, and Matlab in Operations Research (OR) and Excel, Matlab, Minitab, R, and SPSS in Statistical Process Control (SPC). The software choice can be user dependent for the application area in IE, therefore using a single software in any of the IE sub-discipline can be a challenge for students in OR and SPC courses in the case they don't like the software used for solving problems. On the other hand, learning multiple software applications during a 4-month long semester course can be a challenge for students in these courses. On the contrary to its importance, there is little to no attention given to pedagogical research on Industrial Engineering students' software choices. Engineering majors' software choices to solve calculus questions were investigated in several pedagogical research articles however these articles were not focused on industrial engineering students' software application interests.[1, 2]

The importance of meeting students' learning choices and research-based principles of smart teaching is studied in the literature for trying to understand how learning works[7]. Students are observed to be understanding the material thoroughly when instructors' teaching methods match with the students' learning preferences.[3-5] Research indicated relating a task to students' interests results in students placing more value on the task [4, 6, 7] In

addition, students who do not see the value in a goal would either reject or avoid the goal.[4,7] Motivated students strive to get the most from their education by truly embracing new concepts and using them to further advance their knowledge.[7] One of the goals of the surveys analyzed in this work is to observe and understand whether or not students' software learning preferences are met throughout the OR and SPC courses. The instructor chose to teach three software package applications in both courses to observe students' interest in software package applications and determine students' software choice ranking and their reasoning for varying subjects. The qualitative and quantitative data both indicated students' desire to learn different software packages in both courses by the end of the semester. Software packages for both OR and SPC courses are instructed in-class and learning modules are assigned to students as a part of assignment questions.

In this work, students' collected responses to a written questionnaire are analyzed to observe the following:

- SPC students' software choices for solving questions related to data visualization, statistical distributions, diagrams and charts, regression, and correlation after learning how to use Excel, R and SPSS for solving questions related to these SPC concepts.
- Software preferences of OR students for solving linear programming, integer programming, non-linear programming, Markov chains, and linear algebra related questions after learning how to use Excel, Matlab and Lingo for solving questions related to these OR concepts.
- Further investigation of participants' interest in learning more programming languages.

The OR course covered mainly deterministic optimization concepts including linear, integer and non-linear programming and network theory while some of the stochastic concepts are covered from the queueing theory close to the end of the semester. Six Sigma concepts with relevant statistical distribution applications are covered in the SPC course. Students were assigned to solve questions by using all three different software in both OR and SPC courses for several assignments and the semester course projects. The IE students who responded the questionnaires completed an elementary computer science course in the IE program in which they are introduced to basic programming language concepts. The same instructor taught both the OR and SPC courses during the semester of the data collected for this research. There was a total of 8 students willing to participate and complete the research questionnaires analyzed in this work. The participation to this study was voluntary and all the students in both courses participated in this study. Confidentiality of the responses are secured by requesting students to remove any self-identifying information on their written work.

Data Analysis of the Operations Research Software Preferences

Participants of this research enrolled in the junior level OR course and completed a survey to explain their experiences with Excel, Lingo and Matlab software to solve questions related to

1. Linear Algebra
2. Linear Programming
3. Integer Programming
4. Non-linear Programming
5. Markov Chains

In addition to these questions, each student was asked about his/her favorite software in general and if he/she would want to learn other software packages to solve OR questions. Some of the OR course assignment questions required the use of all 3 software packages Excel, Lingo and Matlab. The most extensive assignment

was the semester project which required students to work in groups and solve a real-life problem that they identify by working with an organization which also required all three above mentioned software use (covering ABET criteria 1). Participants' software choices for solving OR problems in this study only depended on small scaled problems with at most 100 variables which was a part of the course project. The quantitative survey results are summarized in Table 1 below.

	Lingo	Excel	Matlab
Linear Algebra	25%	25%	50%
Linear Programming	100%		
Integer Programming	75%	25%	
Non-linear Programming	50%		50%
Markov Chains	50%		50%
Favorite Software	75%		25%

Table 1. The summary of the OR survey participants' software preference percentages

The cumulative/overall preference of the students' extracted from Table 1 is displayed in Figure 1 below. This chart indicates majority of the participants' interest in using Lingo software by Lindo for OR applications while Matlab appeared to be the 2nd and Excel appeared to be the least favorite software. Participants' favorite software choices for all items listed in Table 1 were strongly correlated; high variation only occurred in linear algebra applications for which participants chose all three software for applications. Matlab appeared to be the least favorite software chosen by the participants for linear and integer programming applications while Lingo was the 1st ranking favorite software of the students for OR applications. Matlab was the second favorite choice of the participants except for linear and integer programming applications.

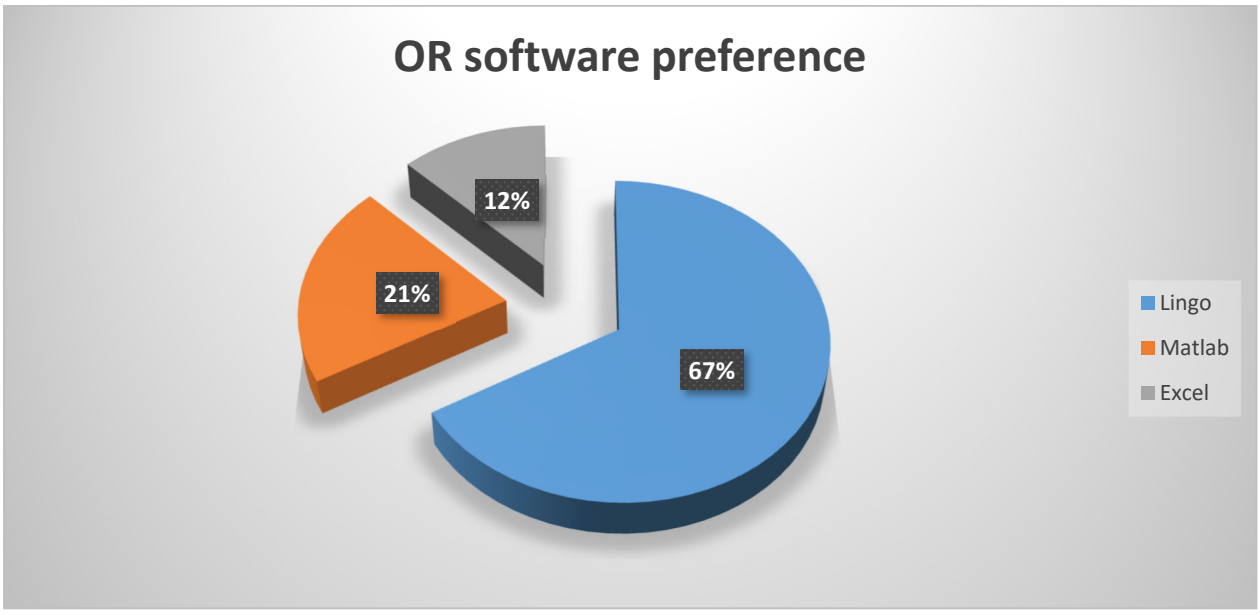
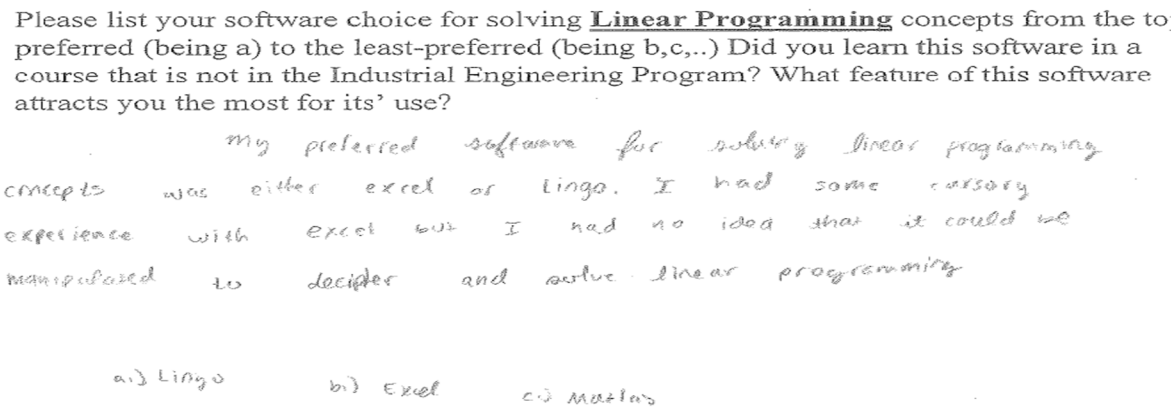


Figure 1. Overall OR software choices of the participants displayed in Table 1

The pie-chart in Figure 1 is an indicator of how important it is to teach more than a single programming language: if Lingo was the only software used for course applications then only 67% of participants would had been pleased with the means to solve the application problems; remaining 33% of the students would had not known other software packages by which they would prefer solving the OR application questions. One of the

research participants, P1, indicates how much he/she was surprised to use Excel for Linear Programming applications by using Excel's Solver.

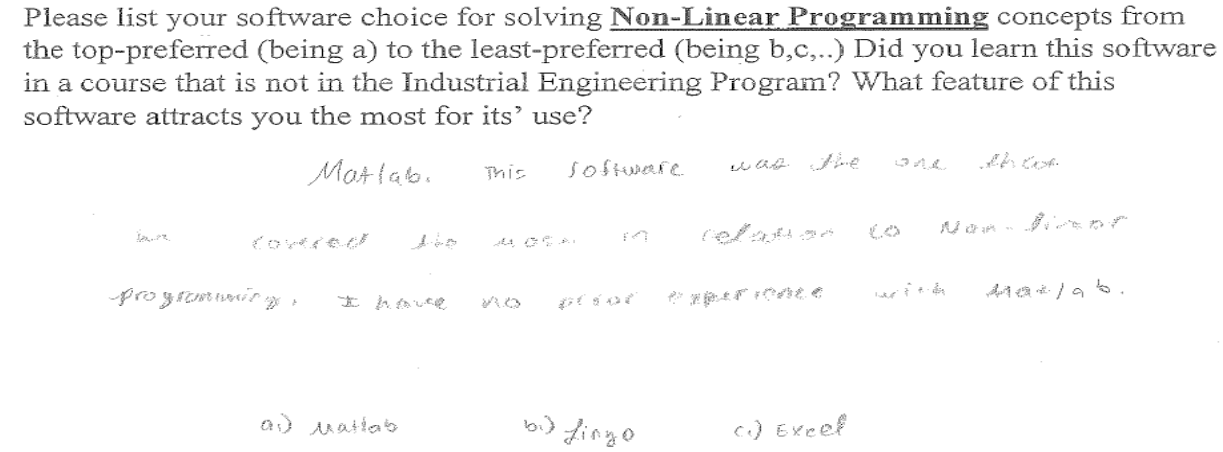

Please list your software choice for solving **Linear Programming** concepts from the top-preferred (being a) to the least-preferred (being b,c,..) Did you learn this software in a course that is not in the Industrial Engineering Program? What feature of this software attracts you the most for its' use?

my preferred software for solving linear programming concepts was either excel or Lingo. I had some cursory experience with excel but I had no idea that it could be manipulated to decipher and solve linear programming

a) Lingo b) Excel c) Matlab

Figure 2. A research participants' reasoning for choosing Lingo to solve LP problems.

P1 showed interest in using Matlab for solving non-linear programming problems as displayed in Figure 3 below.

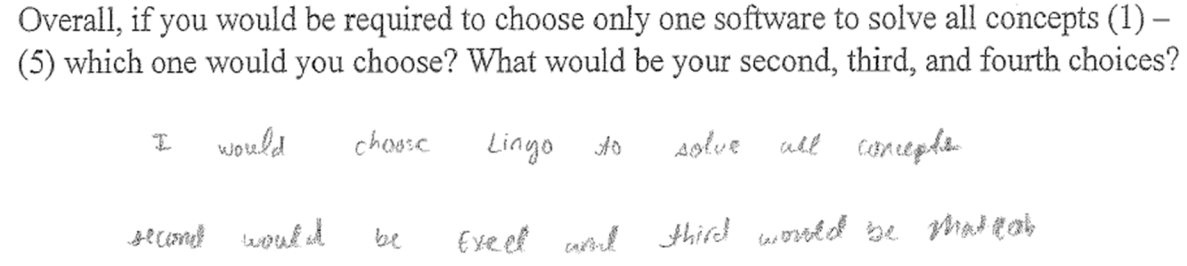

Please list your software choice for solving **Non-Linear Programming** concepts from the top-preferred (being a) to the least-preferred (being b,c,..) Did you learn this software in a course that is not in the Industrial Engineering Program? What feature of this software attracts you the most for its' use?

Matlab. This software was the one which we covered the most in relation to Non-linear programming. I have no prior experience with Matlab.

a) Matlab b) Lingo c) Excel

Figure 3. The reasoning for choosing Matlab for solving non-linear programming problems.

Even though P1 indicated using Matlab for solving problems related to Non-linear Programming concepts, the same participant's "overall" software choice to solve OR concepts (1) - (5) was Lingo. He/she placed Excel as the second-best choice as explained by the participant in Figure 4 below.


Overall, if you would be required to choose only one software to solve all concepts (1) – (5) which one would you choose? What would be your second, third, and fourth choices?

I would choose Lingo to solve all concepts

second would be Excel and third would be Matlab

Figure 4. P1's "overall" software choice for solving OR concepts (1)-(5).

Changing the use of software package from Lingo to Matlab when linear programming changes to non-linear programming is an important outcome of this study; even though students learn multiple software packages to solve a variety of problems, their ability to critically choose which program to be used when and how is a valuable experience for them. Participant P2 indicated Excel to be his/her favorite software to be used for OR applications due to its ease of use, his/her choices to solve OR questions was a combination of Excel, Lingo and Matlab. A surprising aspect of P2's response is preferring to solve linear and non-linear programming problems by using Lingo while preferring to solve integer programming problems by using Matlab.

Correlation Analysis of the OR Data

Correlation analysis of students' software choices for OR applications and survey data will be performed in this section. The following correlation outcomes for the data collected from the OR survey are observed:

1. There wasn't a strong correlation between software choices of all participants for all (1)-(5) OR concepts: Students didn't have the same interest in the same software for the same application except LP.
2. Students who preferred to use Lingo for linear programming also preferred to use Lingo either for integer or non-linear programming problems' solutions.
3. A high correlation coefficient is attained for Lingo as the first choice of the students for programming at least three of the five concepts listed in (1) – (5) above while Excel being the second best choice.

Some of the factors that could impact the correlation outcomes listed above are the following:

1. An Excel template is shared with students for linear and integer programming solutions and Excel solver is used for preparing this template.
2. Optimization toolbox of Matlab is used for assignment solutions and in-class activities; this method did not require extensive knowledge of computer programming.
3. Lingo was installed by students in their laptops therefore it was easy for them to use for solving problems.

The qualitative data analysis indicated Lingo to be the favorite choice of students for its' ease of use. Students were able to write codes in Lingo to solve problems by simply typing the mathematical model that is almost identical to the way they formulated the problems. The following graph displays an example of a Lingo 17.0 code written by a student group to solve one of the course projects.

Matlab, the second-best software choice of the participants, required minimal amount of programming and Matlab coding knowledge; the optimization toolbox is used for solving problems which mainly required basic knowledge of entering vectors, matrices and mathematical functions in Matlab. The last choice, Excel, only required the data entry in a certain template to solve linear programming problems; Excel was not instructed in this course to solve non-linear optimization problems.

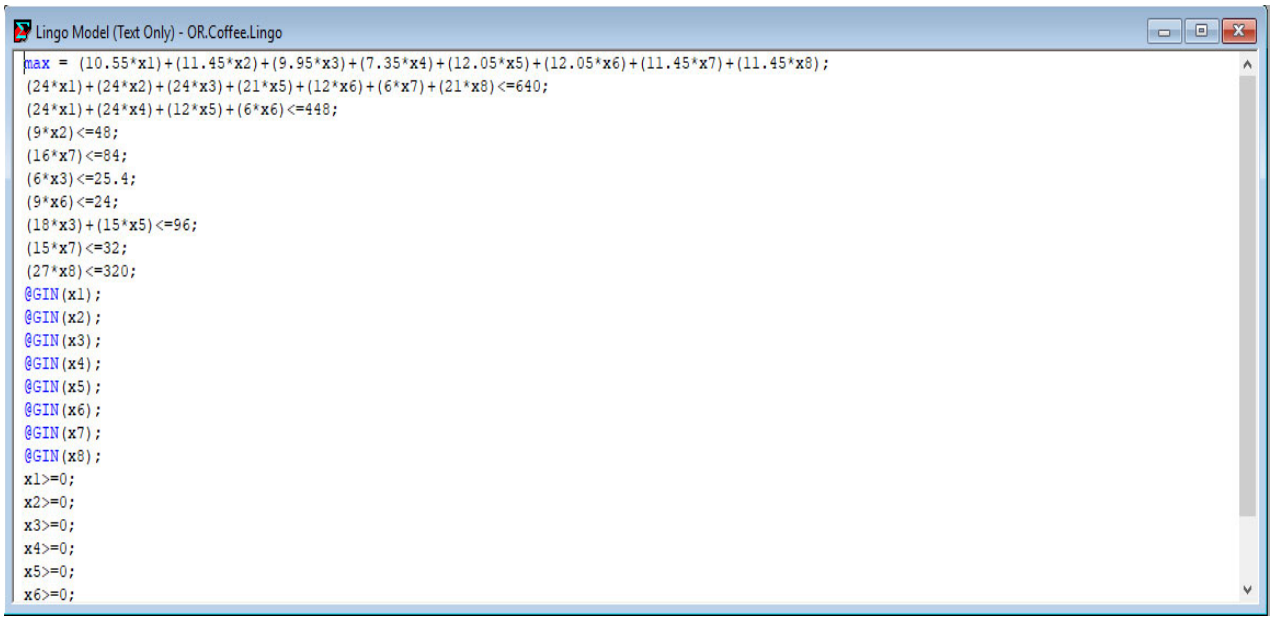


Figure 5. An example of a Lingo software code written by two students to solve a problem

Data Analysis of SPC Software Preferences

The junior level SPC course registered students' experiences with Excel, R and SPSS to solve questions related to the following concepts will be analyzed qualitatively and quantitatively in this section:

1. Data visualization
2. Statistical distributions
3. Diagrams and charts
4. Regression and correlation analysis
5. Control charts

The research participants were asked to rank their favorite software choices based on the concepts (1) – (5) listed above. Table 2 below outlines top software ranking of the participants to solve the corresponding concepts in SPC.

	Excel	SPSS	R
Data visualization	20%		80%
Statistical distributions	80%	20%	
Diagrams and charts	60%		40%
Regression and correlation analysis	80%		20%
Control charts	100%		

Table 2. Summary of the participants' top software choices to solve SPC related questions.

Figure 6 displays overall percentage distribution of the participants' software choices for all concepts covered in Table 2. Similar to the software preferences of the OR students, about one-thirds of the research participants preferred to use more than one software for solving SPC problems which is an indicator of how important it is to learn multiple software solutions for solving questions related to SPC. Four fifths of the participants' interest to use R software instead of Excel for Data Visualization stands out in Table 2 when it is compared to the

corresponding percentages of participants' interest to use R software for concepts (2)-(5). Forty percent of the research participants had prior R programming knowledge as a part of the statistics course they successfully completed therefore the information displayed in Table 2 may be biased due to these students' prior knowledge and experiences. All the research participants except one completed the basic computer science course required for the Industrial Engineering students; however, the completion of this course did not impact this participant's software preference.

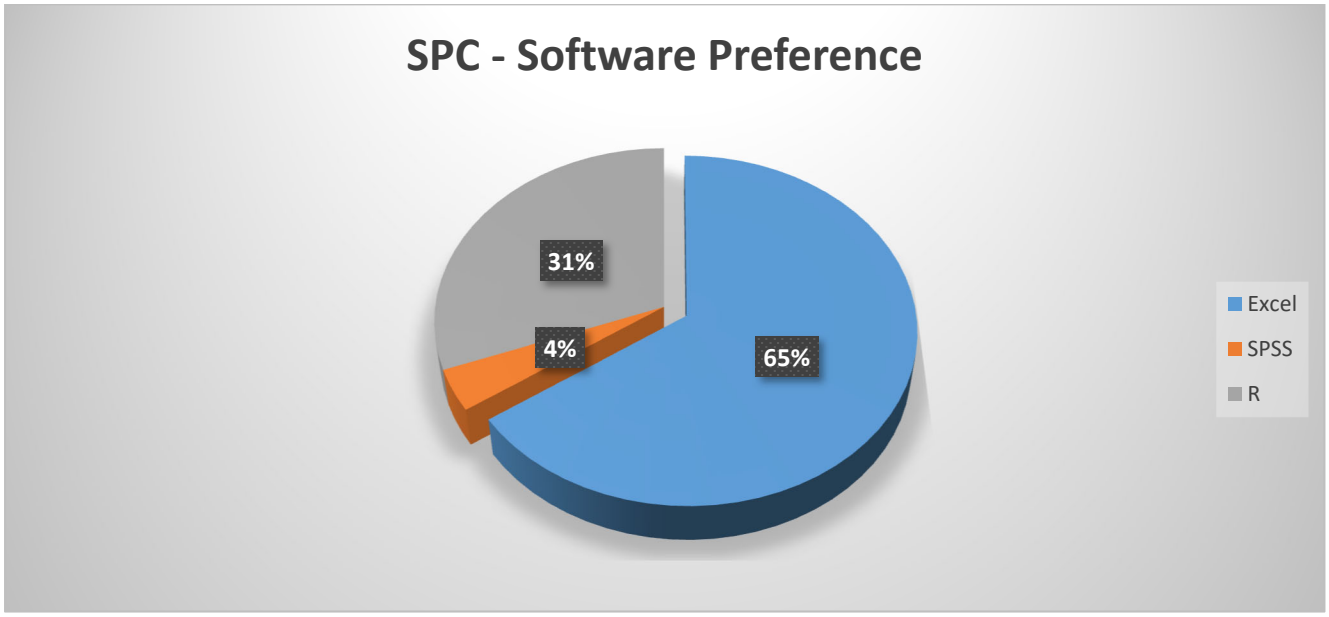
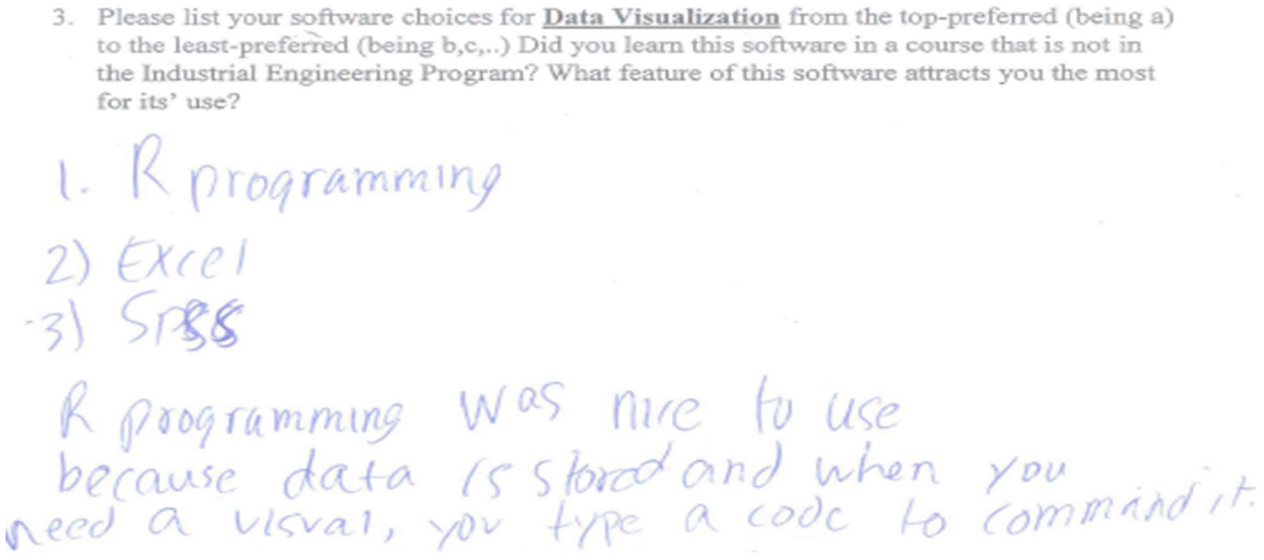


Figure 6. The probability distribution of the SPC research participants' Excel, SPSS and R software preference

Research participant P9 preferred R software package due to its "data storage" and ease of coding to be able to visualize the data without the data set; this participant's response is explained in Figure 7 below.


3. Please list your software choices for **Data Visualization** from the top-preferred (being a) to the least-preferred (being b,c,..) Did you learn this software in a course that is not in the Industrial Engineering Program? What feature of this software attracts you the most for its' use?

1. R programming
2) Excel
3) SPSS

R programming was nice to use because data is stored and when you need a visual, you type a code to command it.

Figure 7. Research participant P9's software preference for data visualization.

Another participant chose Excel to visualize data sets due to his/her prior experiences in Excel as displayed in Figure 8 below.

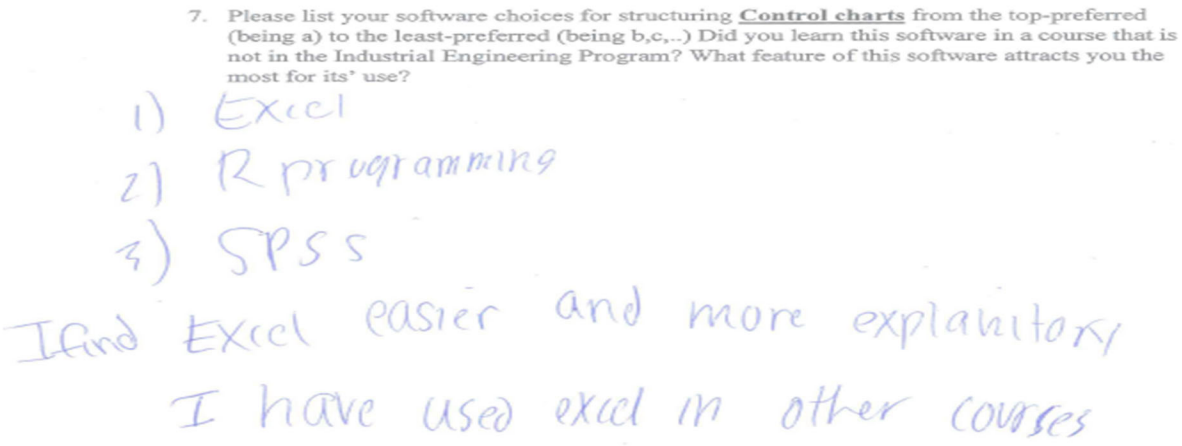


Figure 8. An IE student's response to a software choice question for control chart drawing.

A reason that participants may not preferred to use SPSS could be due their difficulty to access the software via a virtual desktop. This virtual desktop requires connecting to the university network therefore adding another layer of network connection to be able to use the software. This issue was mentioned by one of the participants in the OR research survey for accessing the virtual desktop to be able to use Matlab.

Correlation Analysis of SPC Questionnaire

Correlation analysis of students' SPC related software choices and survey data will be performed in this section. The following qualitative and quantitative outcomes are attained from the collected SPC survey data:

1. There appeared to be 100% R^2-value (i.e. high) correlation value attained for the students who would want to learn more programming and chose R software for data visualization.
2. A strong correlation between students' interest in the use of Excel for doing regression and correlation analysis and using Excel for control charts is observed. The same correlation observation does not apply to other items (1)-(3) listed above.
3. A strong correlation on students' least and most favorite program preferences is observed when all (1)-(5) items listed above are considered as a whole: Two students found SPSS to be the least favorite program to be used for all (1)-(5) items while R appeared to be the least favorite of one of the students.
4. Those students who found Excel useful for implementing some of the concepts (1)-(5) also found R software to be useful for the rest of the items (1)-(5) listed above.
5. Students had lack of interest in code-driven SPC solutions; for instance, R software required writing several lines of code for achieving the corresponding results.

The following are some of the factors that could impact the correlation outcomes listed above:

1. SPSS software was accessible only via a virtual desktop that had to be used by the students using internet. Some of the participants expressed this as an "annoying factor" of the use of the software.
2. MS Excel was provided to all students by the university to install in their laptops therefore it was easy for participants to use Excel.
3. The instructional methodology to teach the software:
    a. MS Excel is taught in the classroom with hands-on activities.
    b. SPSS is instructed to students via video recordings and in-class lectures.
    c. R is instructed students via readily available resources in the internet.

Students are assigned to solve software-driven SPC problems in parts of the course assignments as well as the semester project of the course. The assignment questions were instructor's own questions that could not be

found in textbooks. The course project required students to work in groups to identify and solve a problem by working with a manufacturer, health care provider or service provider in the area. Students had the freedom to choose the software package for their in-class presentation and the written report. All project groups used a mix of the software packages they learned for completing the course project.

Overall Software Preferences of the IE Students

Participants had different software package choices for solving OR and SPC related problems. Students' desire to choose multiple software packages for solving problems in both courses and learn more software packages in addition to the three software packages indicated their high motivation towards learning and using more technology. One of the research participant's software choice appeared to be driven by "getting comfortable with"; Lingo was chosen by this participant for its ease of use.

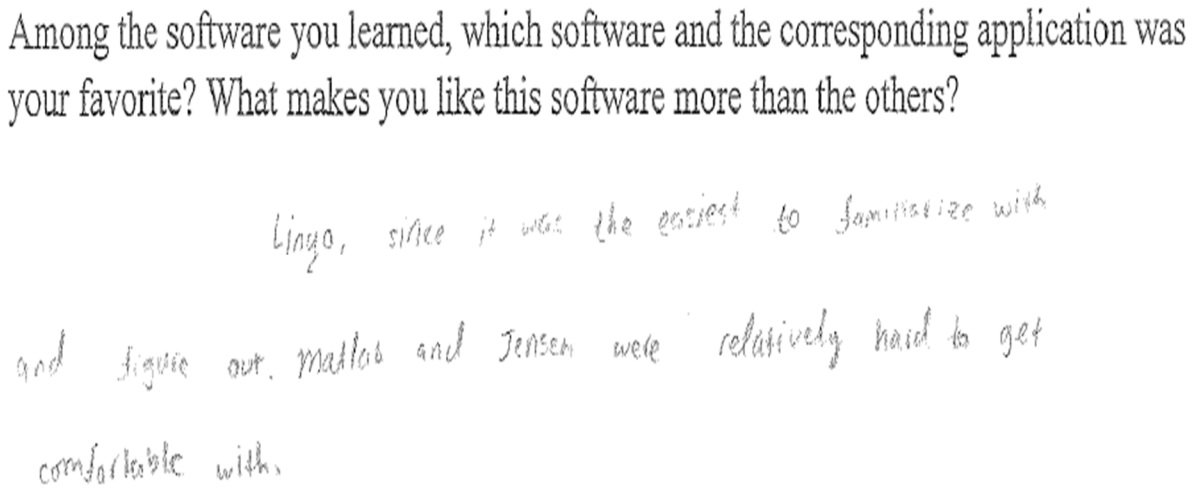


Figure 9. A participant's favorite software choice was Lingo for solving OR questions.

The appreciation of learning a variety of software packages and desire to learn more is indicated by participant 2 in Figure 10 below.

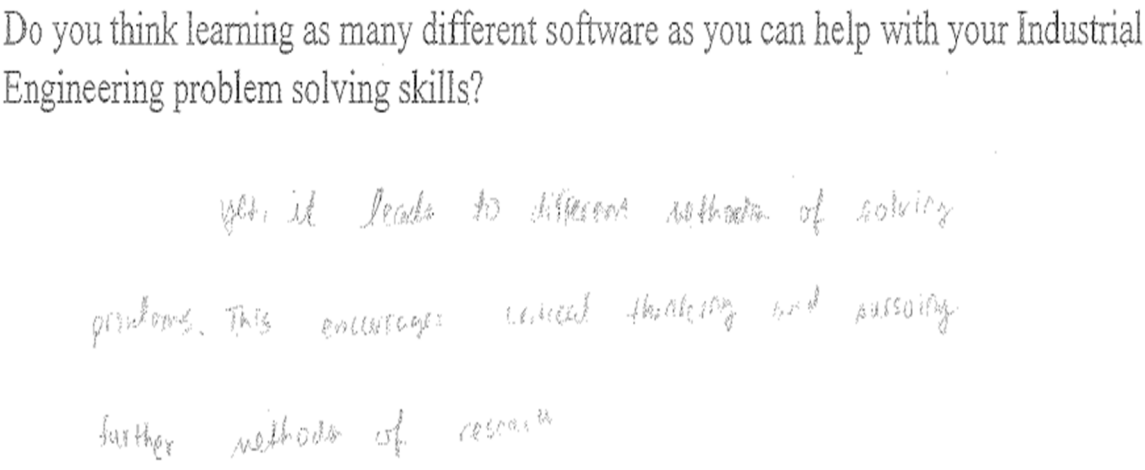


Figure 10. P2's desire to learn additional OR related software package.

Conclusion & Future Work

Industrial Engineering undergraduate students' technology/programming preferences for learning OR and SPC concepts and solving related questions in these areas of interest are covered in this work. The data is collected during a particular semester in an Industrial Engineering program located on the Northeastern side of the United States; both qualitative and quantitative data analysis is performed. The same instructor taught OR and SPC courses during the same semester and three software packages were covered in each course for various conceptual applications. The software application areas in OR included

1. Linear Algebra
2. Linear Programming
3. Integer Programming
4. Non-linear Programming
5. Markov Chains

and the software application areas in SPC included

1. Data visualization
2. Statistical distributions
3. Diagrams and charts
4. Regression and correlation analysis
5. Control charts

The analysis of the collected data indicated the following outcomes for both courses:

- Research participants' software preferences for solving different conceptual questions within the same course varied; students benefited from learning various technologies to solve problems.
- The technology choice of the participants was mainly focused on two of the technologies taught for both courses; however, participants' preferences varied: For example, Excel and SPSS were favorite choices of one of the participants while Excel and R were the top two choices of another participant.
- Lingo for OR related concepts and Excel for SPSS related concepts appeared to be the top choices of the majority of the participants for technology use.
- The technology preferences of the students were driven by the easy use of the corresponding technology and the number of steps required by the software to solve the problems. For instance, Lingo appeared to be easy for entering the formula for solving a linear programming problem (which was the most popular choice for solving linear programming problem) while Excel had a more complicated structure for solving the same problem that required more steps to enter the information.
- Accessing the software via a virtual desktop appeared to lower the popularity of the corresponding software for solving problems in both OR and SPC.

There were only two students taking both courses and these students' software preferences were different for both courses even though Excel was common in both courses.

The qualitative and quantitative results derived in this article indicated the importance of teaching various software packages to strengthen students' software knowledge. Teaching three different software packages to solve questions in both OR and SPC courses helped students to choose their favorite software for solving problems based on the corresponding concepts. Educators can use the methodologies explained in this work as a benchmark to improve their coursework and modify the contents if they see a need for it. The results displayed in this work is a gateway to have a better understanding of what OR and SPC students prefer to choose for them to add more value to the tasks they need to complete. As research indicates, relating a task to students' interests

results in students placing more value on the task [4, 6, 7] In addition, students are observed to be understanding the material thoroughly when instructors' teaching methods match with the students' learning preferences.[3-5] These literature results and the data analysis results attained in this article indicate replacing Excel in OR course and SPSS in SPC course with other software packages. This change can increase students' motivation and help them to place more value on the tasks they need to complete for both courses. The other researchers are also encouraged to explore their students' software choices and replace the software in their courses (if needed) for providing a better learning experience to their students.

References

[1] E. Tokgöz, "Technology Choices of Undergraduate Engineering Students for Solving Calculus Questions", ASEE Annual Conference Proceedings, paper ID # 17810, 2017.

[2] E. Tokgöz, "Undergraduate and Graduate STEM Majors' Technology Preference for Solving Calculus Related Questions," ASEE Annual Meeting Proceedings, Seattle, Washington, Paper I.D. #: 12668, 2015.

[3] R. M. Felder and R. Brent, "Understanding Student Differences," *Journal of Engineering Education*, vol. 94, no. 1, pp. 52-72, 2005.

[4] R. M. Felder and L. K. Silverman, "Learning and Teaching Styles in Engineering Education," *Engineering Education*, vol. 78, no. 7, pp. 74-681, 1988.

[5] R. M. Felder, "Reaching the Second Tier: Learning and Teaching Styles in College Science Education," *Journal of College Science Teaching*, vol. 23, no. 5, pp. 286-290, 1993.

[6] T. A. Litzinger, L. R. Lattuca, R. G. Hadgraft, and W. C. Newstetter, "Engineering and the Development of Expertise," *Journal of Engineering Education,* vol. 100, no. 1, pp. 123- 150, 2011.

[7] S. A. Ambrose, M. W. Bridges, M. DiPetro, M. C. Lovett, and M K. Norman, *How Learning Works 7 Research-Based Principles for Smart Teaching*, San Francisco: John Wiley & Sons, 2010.