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"USE OF ELECTRONIC SPREADSHEETS TO FACILITATE CRITICAL THINKING IN QUANTITATIVE COURSES: A 25-YEAR UPDATE"

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Abstract

Students must improve critical thinking skills throughout their college curriculum at the undergraduate, graduate and professional school levels. Critical thinking skills are essential to innovators and decision makers in business, health care, engineering, government and many other disciplines. The effective decision maker must ask these questions for complex decisions and processes:

- Why are the results what they are?
- What is the range of feasible results?
- Do these results effectively solve the problem?
- What are the risks and how do we mitigate them?
- Can we improve upon the solution?
- Can we eliminate adverse side effects?

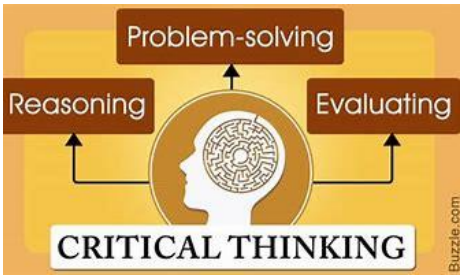
Critical thinking skills often involve scenario analysis or "what if" analysis of numerical results. It is too common to get overwhelmed by scenario analysis but electronic spreadsheets such as Microsoft Excel, Google Sheets or Open Office can provide valuable insight if implemented effectively. Mathematics is critical but the focus must be on the analytics based upon the mathematics. For important decisions, electronic spreadsheets can be valuable complements to critical thinking skills.

Keywords

Critical Thinking Skills, Electronic Spreadsheets, Scenario Analysis

Introduction and Literature Review

This paper is an update to one that I had written about 25 years ago (Ono, 2001).



"Critical Thinking - The ability to think in a way that is clear, reasoned, reflective, informed by evidence, and aimed at deciding what to believe or do. Dispositions supporting critical thinking include open-mindedness and motivation to seek the truth." (Pacific Oaks College, 2024)

Students must master critical thinking skills to be effective innovators and decision makers in their professions. The basic premise regarding critical thinking skills has not changed but the strength and complexity of critical thinking analytics can be enhanced using modern functionalities. Computer software has advanced tremendously over the last 25 years so these tools should be used to add depth and clarity to critical thinking skills.

While software acumen is important, software acumen is not a substitute for critical thinking skills. One can be highly skilled in a software application but that is not a substitute for critical thinking. Critical thinking skills represent higher level analytics, something that current software cannot duplicate. Maybe artificial intelligence (AI) will master critical thinking skills in the future, but we are not at that point yet. Critical thinking skills remain the upmost priority for our students regardless of their academic discipline.

Critical thinking skills go beyond the checklist shown in the Abstract at the beginning of this paper. It requires deep introspection that is best supported by quantitative analysis. Electronic spreadsheets can be more than just advanced calculators, they can convey decision sciences insight and communicate complex solutions.

Critical thinking skills are of upmost importance in failure analysis. There could be very difficult answers to the question "Why isn't this working?" The ultimate goal is to succeed but failure is an inherent part of any complex process. This has to be accepted and planned for. The key is to learn from failure and critical thinking skills should be a key in the learning process. Quantitative results from electronic spreadsheets can greatly assist in the failure analysis process. Electronic spreadsheets should be an integral part of failure analysis from the very beginning of the failure analysis study. Electronic spreadsheets can be an effective measure to quantify failure analysis, to display results and to store data and results.

A Japanese saying is, "If you get on the wrong train, get off at the nearest station. The longer it takes you to get off, the more expensive the return trip can be." (outlook.live.com, 2024). The key takeaway from this saying is that timing is important and that it is crucial to identify problems as early as possible. Don't allow small problems to become big problems. Critical thinking skills are not satisfied only with the status quo, critical thinking skills should assist in problem identification. "If it's not broken don't try to fix it" doesn't always apply. Be proactive not reactive in problem identification. A squealing rubber belt in a car engine could indicate more problems within the engine. Replace the belt first but investigate further to see if there is a deeper underlying problem. Applying critical thinking skills here can prevent a car breakdown at the worst possible moment. This car analogy applies to all complex processes.

About 25 years ago I had written a journal article about the integration of electronic spreadsheets into critical thinking skills (Ono, 2001):

"https://www.academia.edu/109681224/Use_of_Electronic_Spreadsheets_to_Facilitate_Critical_Thinking_in_Quantitative_Courses."

This was a novel idea at the time because electronic spreadsheets were not widely implemented back then but their applications were increasing and usage was on an upward trajectory.

Another problem was that laptop computers were rare at that time. Most students didn't have laptops so any courses that required electronic spreadsheets needed to be conducted in classrooms specifically designed with desktop computers in them. Those class sizes were limited to the number of desktop computers in those classrooms. Desktop computers with their cathode-ray terminals were space-eaters in classrooms with limited space. Cable management was also an impediment to student population size in a course.

Fast forward from the late 1990's to today and those types of classrooms are almost dinosaurs now. Most students have their own laptops and those who do not can borrow laptops from the school library. Today's laptops are much more powerful than personal computers were 25 years ago and have a much wider range of functionalities. It's hard to imagine what laptops will evolve into over the next decade but we know that their power and functionality will increase greatly with a corresponding decrease in size.

Most importantly, students understand that mastery of software is a foundation to their career success and many are eager to learn software. Many students become highly efficient in operating software and courses like accounting, statistics, engineering, etc., are often hybrids between the academic

topic and the corresponding software. Students understand the importance of mastering various software and their application within their academic discipline.

Maybe critical thinking skills cannot be taught but they can be greatly augmented. Electronic spreadsheets are tools to achieve this.

Literature reviews are inserted into the appropriate sections in addition to the above.

Traditional Methods

I demonstrated the traditional implementation of electronic spreadsheets in my original publications using business and engineering examples (Ono, 2001). The traditional implementation of electronic spreadsheets remains popular and is difficult to improve upon. The traditional implementation of electronic spreadsheets can deliver in-depth, robust and intuitive insights in the scenario analysis of potential alternatives. The coding of problems in the spreadsheet can be complex and should be tested for accuracy and reliability; however, once this has been established, the improvement of critical thinking skills is greatly enhanced.

Good coding skills must be adhered to. The spreadsheet must "cell reference" in each and every instance so that the spreadsheet will "flow down" once changes are made to initial inputs. Make the change at the top of the spreadsheet to as few of the inputs as possible, then allow the electronic spreadsheet to automatically update the subsequent calculations. This is a key consideration in complex spreadsheets.

In the following example we will perform scenario analysis for an income statement in contribution margin format. We will assume that price per unit, variable cost per unit and total fixed costs will remain constant over the relevant range. The only factor that varies in this scenario is the number of units sold. We would like to determine the change in earnings before interest & taxes based on the change in the number of units sold.

In the original scenario 10,000 units are sold:

INCOME STATEMENT
CONTRIBUTION MARGIN FORMAT
(Base)

# of Units Sold		10,000	units
Price per Unit	$	100	
Total Revenues			$ 1,000,000
# of Units Sold		10,000	
Variable Cost per Unit	$	65	
Total Variable Cost			650,000
Contribution Margin			350,000
Total Fixed Cost			400,000
Net Operating Income			$ (50,000)

In the "what if" scenario 12,500 units are sold and the company is profitable, unlike the original scenario. All that needed to be done in the "what if" scenario was to change the number of units from 10,000 to 12,500 then the electronic spreadsheet automatically updated.

INCOME STATEMENT
CONTRIBUTION MARGIN FORMAT
(Scenario)

# of Units Sold	12,500	units
Price per Unit	$ 100	
Total Revenues		$ 1,250,000
# of Units Sold	12,500	
Variable Cost per Unit	$ 65	
Total Variable Cost		812,500
Contribution Margin		437,500
Total Fixed Cost		400,000
Net Operating Income		$ 37,500

only need to make a change here

One simple change to the spreadsheet provides valuable insight. It would have been time consuming to reconstruct the income statement based upon the "what if" scenario. A key difference is that the original scenario lost money while the "what if" scenario was profitable. Critical thinking should ask the question: "How do we sell 2,500 more units in an economically feasible fashion? What are the risks involved?" In-depth analysis should then commence.

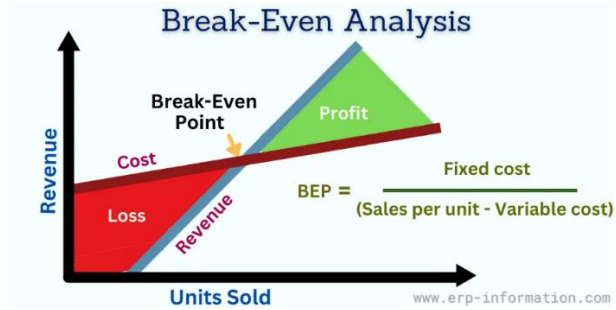
Important metrics can be derived from the original and the scenario (Ono, 2001). We can calculate the percentage change in earnings before interest and taxes divided by the % change in the number of units sold. This ratio is called an elasticity and is a common decision-making variable in economics and engineering. It is important to know if this metric is elastic or inelastic and the benefits and drawbacks to each. Use of elasticities will accelerate future decision-making but we see that the base calculations are performed using an electronic spreadsheet.

ELASTICITY

% Change in Net Operating Income	175%
% Change in # of Units Sold	25%
Elasticity	7

highly elastic
"Net Operating Income" sensitive to "# of Units Sold"

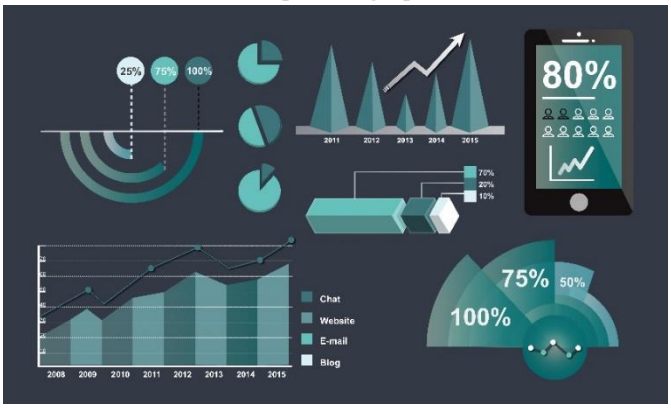
This spreadsheet can then be extended to Cost-Volume-Profit Analysis and Target Profit Analysis, which are essential business calculations. The original and scenario spreadsheets can be much more complex and therefore more realistic, but electronic spreadsheets make scenario analysis accurate and reliable.



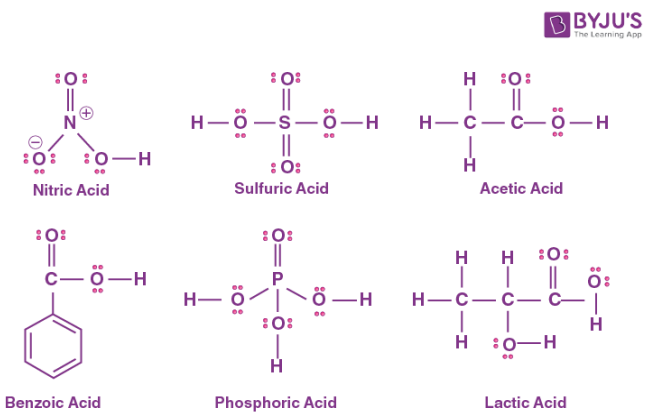
This is just a single example of the use of "Traditional Methods" to stimulate critical thinking skills in your instruction, there are a host of other examples. Use your experience and subject matter expertise to build instructional modalities that most benefit your class. Your acumen in this academic topic will enhance the quality of your instruction and further develop the critical thinking skills in your students.

Graphics

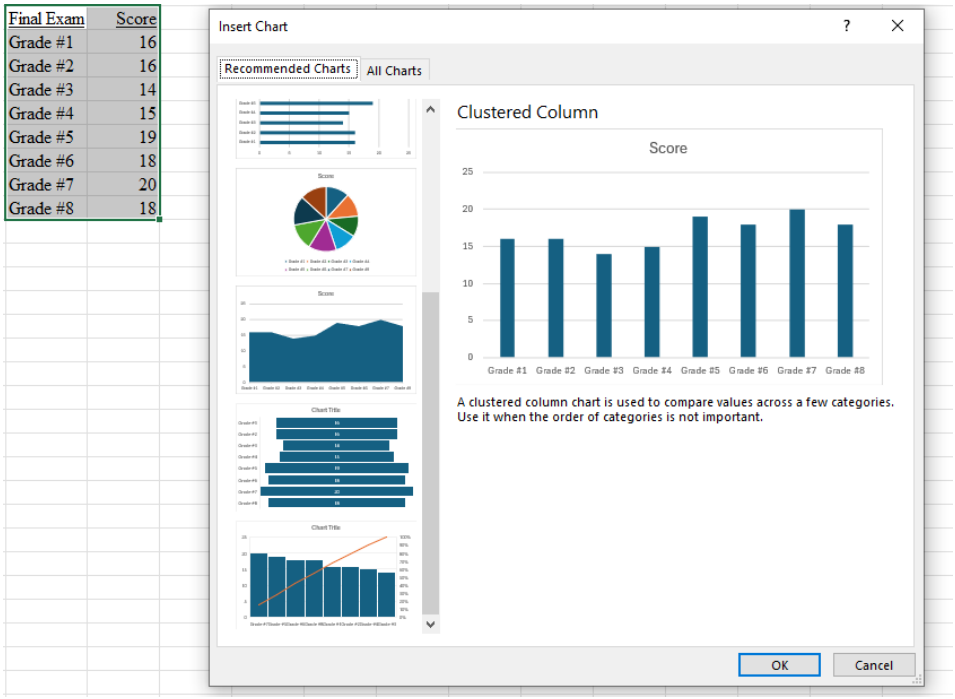
The effectiveness and impact of graphics cannot be underestimated. Graphs are excellent visualizations to communicate complex methods and results in a straightforward manner. Graphics capabilities have always been available in electronic spreadsheets but their ease-of-use has increased tremendously in the past decade.



In the past, graphs were best constructed with software specifically designed for graphics. Graphic software were robust and could build stunning graphics. The finished product was then "cut & paste" into the appropriate document. This was straightforward and fairly simplistic, but it required two different software applications to incorporate the graph with its narrative and/or its spreadsheet. Graphical inserts were an additional step in the overall process.



To create a graph, the user must organize and cleanse the data, then identify the data to be graphed. Microsoft Excel will then give graph recommendations based upon the data. Below is the graphics dialog box from Microsoft Excel with recommendations:



The recommendations generally are good and provide the user with some ideas that the user may not have considered initially. If the user is not satisfied with the recommendations, the user can create their own graph using the robust graphics capability currently available in Microsoft Excel.

This is just a single example of the use of "Graphics" to stimulate critical thinking skills in your instruction, there are a host of other examples. Use your experience and subject matter expertise to build

instructional modalities that most benefit your class. Your acumen in this academic topic will enhance the quality of your instruction and further develop the critical thinking skills in your students.

Students should be encouraged to use graphics in their analysis to strengthen the critical thinking process through visualizations. It takes some effort to construct and refine graphics but it is worth the effort. Graphics are a "best practice".

SOLVER

In the early 1990's the SOLVER add-in program was developed for Lotus 1-2-3. When my original paper was written in the late 1990's the SOLVER add-in program wasn't even 10 years old but still possessed powerful functionality. The original SOLVER add-in program took some practice to become proficient at but it was a small sacrifice if one wanted to access the power of the SOLVER add-in program. Because of this learning curve the SOLVER add-in program wasn't as popular as it is today and was somewhat underutilized.

In the early 2000's upgrades were made to the SOLVER add-in program to make it much more user friendly (www.solver.com, 2024). The functionality wasn't improved significantly but the SOLVER add-in program ease-of-use was greatly enhanced. Because of this increased accessibility, use of the SOLVER add-in program became much more commonplace. Problems which were mathematically complex could now be addressed without a background in engineering and quantitative methods to derive insights that were intuitive and imminently implementable. Practitioners could focus on the "big picture" without getting bogged-down in the differential equations. Critical thinking skills are enhanced.

Constrained optimization problems, specifically linear programming problems, are now straightforward to perform using the SOLVER add-in program. Most of those who practice operations research or management science are generally well-versed with optimization software such as AMPL or LINDO. These software, however, are proprietary and require a license to operate these, which makes them inaccessible to many users. Coding AMPL or LINDO is not easy and requires knowledge about the program's architecture. The optimization software are necessary for large-scale problems with hundreds of decision variables, but small to medium constrained optimization problems can be performed by the SOLVER add-in program because the SOLVER add-in program is robust. It will require some precise electronic spreadsheet coding but this is a better alternative than having to purchase expensive optimization software.

A good example would be linear programming, specifically integer programming. In this example a pharmaceutical company produces two drugs which have common ingredients so the pharmaceutical company wants to determine the optimal combination of the two drugs to produce. The pharmaceutical company wants to maximize its profits and Drug X has a profit of \$40 per unit while Drug Y has a profit of \$50 per unit. The constraints represent limited availability of personnel and machine hours so waste is minimized.

Solve the linear programming problem in two ways:

Maximize $P = 40x + 50y$

Subject to:

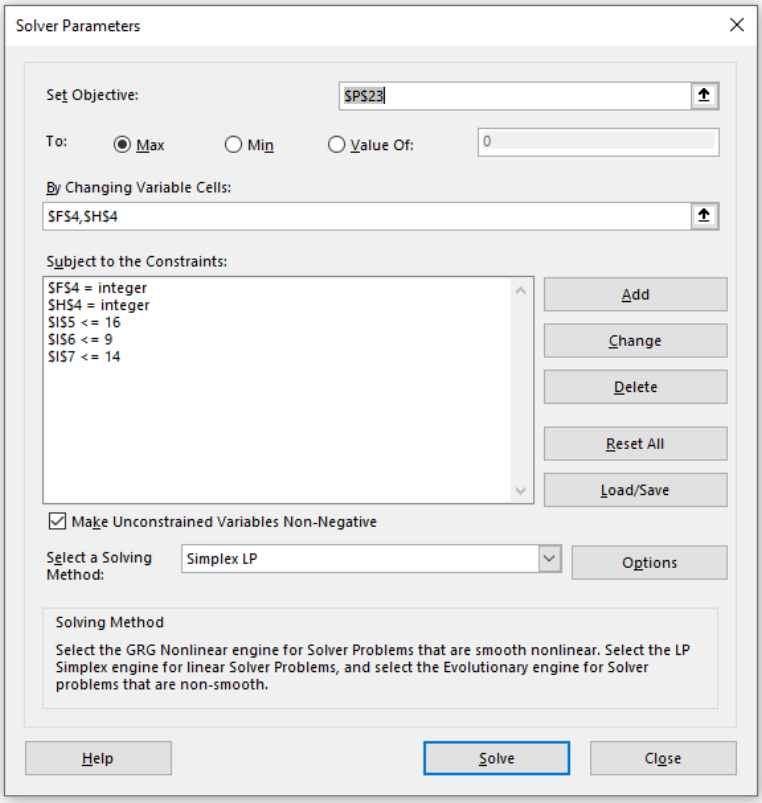
$$2x + y \le 16$$
$$x + y \le 9$$
$$x + 2y \le 14$$
$$x, y \ge 0$$

1. Find the graphical solution.
2. Use the simplex solution to find the solution.

Integer linear programming problems are difficult to solve. This will be formulated as an integer linear programming problem because any partial units are wasteful so only full units are produced. Integer programming adds another layer of complexity because "Cutting Planes Algorithms/Gomory Cuts" are commonly deployed (Gomory, 1963). "Cutting Planes Algorithms/Gomory Cuts" are multifaceted and require technical expertise to correctly implement. This is only a simple example so the graphical solution and the simplex solution are doable manually but would still be time-consuming. This is also a mistake-prone process unless strict error prevention measures are taken. The original Excel formulation with the SOLVER dialog box is presented:

PHARMACEUTICAL PROBLEM

	X Coef	X	Y Coef	Y	Total	Max/Min	
Objective Function	40	0	50	0	0		
Subject To	2	0	1	0	0	≤	16
	1	0	1	0	0	≤	9
	1	0	2	0	0	≤	14



Here are the results of this integer programming problem:

PHARMACEUTICAL PROBLEM

	X Coef	X	Y Coef	Y	Total	Max/Min	
Objective Function	40	4	50	5	410		
Subject To	2	4	1	5	13	≤	16
	1	4	1	5	9	≤	9
	1	4	2	5	14	≤	14

The SOLVER function calculated a value of 4 units for Drug X and 5 units for Drug Y. Profits are maximized at $410 for this pharmaceutical company. Constraint 2 and Constraint 3 are binding but Constraint 1 will have slack. The values are optimized so the maximum profit cannot be improved upon without changing the constraints.

Critical thinking skills and scenario analysis are complementary at this point. Experiment with different resource availability combinations to determine if greater profits can be generated. Query with different profit per unit scenarios to test if greater profits can be derived. Scenario analysis can make a significant contribution to critical thinking skills.

Specialized optimization software would have generated the same results but the specialized optimization software is not accessible to those without the appropriate license while electronic spreadsheets are widely accessible. Large-scale programs require specialized optimization software such as LINDO or AMPL, especially if constrained optimization is performed frequently. Some of these large-scale programs need to be performed by specialists who have extensive backgrounds in mathematics and

operations research. Small to medium sized optimization problems, however, lend themselves well to a SOLVER add-in program and the SOLVER add-in program can add valuable insight through scenario analysis. Critical thinking skills are enhanced without being overwhelmed with tedious mathematical calculations which can be time-consuming if done manually.

This is just a single example of the use of "SOLVER" to stimulate critical thinking skills in your instruction, there are a host of other examples. Use your experience and subject matter expertise to build instructional modalities that most benefit your class. Your acumen in this academic topic will enhance the quality of your instruction and further develop the critical thinking skills in your students.

Pivot Tables

Pivot tables were developed in the early 1990's and were another tool that was evolving in the late 1990's, the time of my original paper (productivityhub.org, 2021). Since then, pivot tables have progressed to become much more user-friendly and therefore have become accessible to most electronic spreadsheet users.

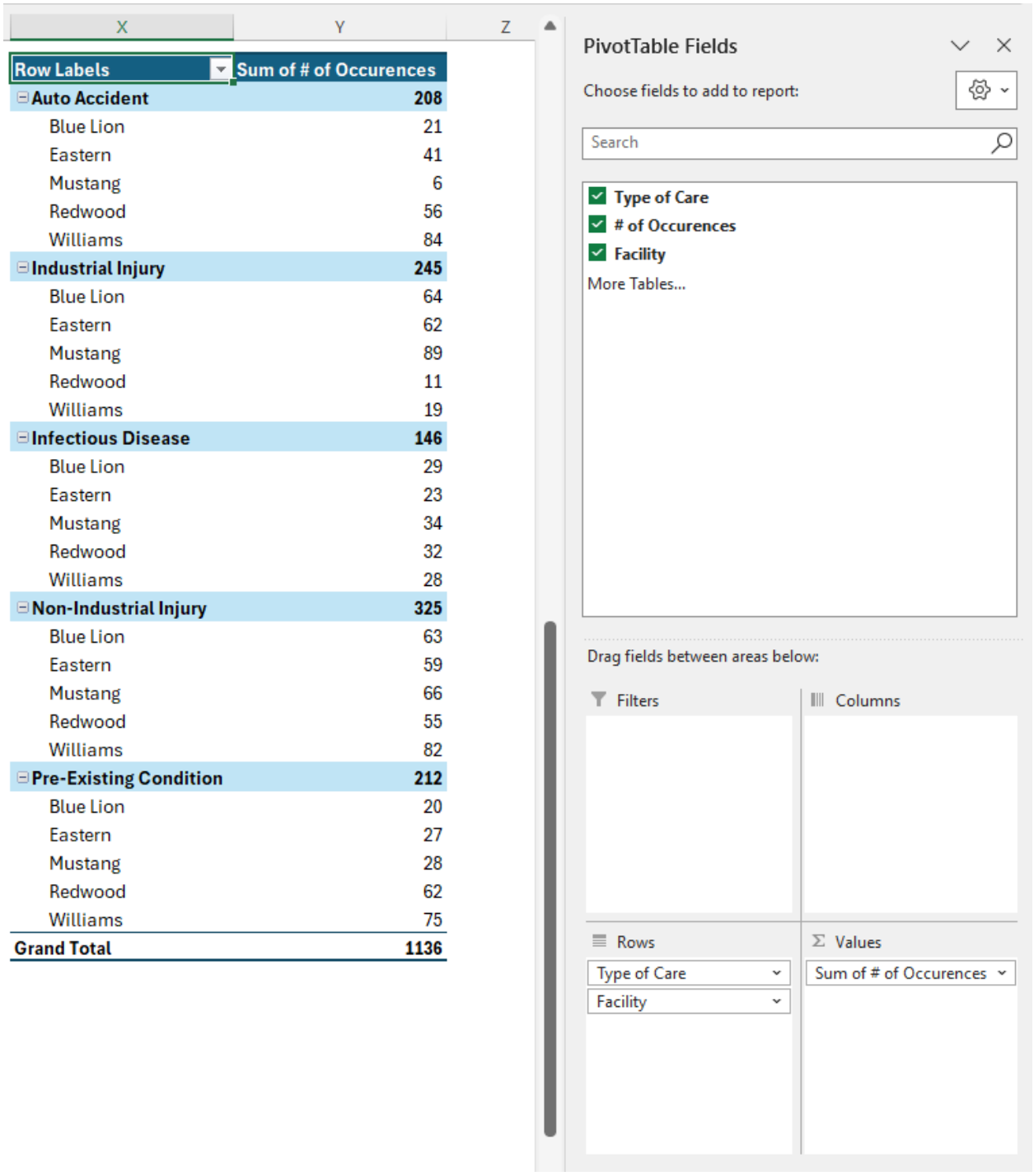
Pivot tables create summary tables from other tables. This process can be performed manually but this is time consuming and prone to errors. Pivot tables allow the analyst to go from the "specific to the general"; it is a method to summarize summary tables. Pivot tables allow the analyst to avoid the "can't see the forest for the trees" problem and to develop a holistic picture of the overarching issue.

In the following example the company shows (1) type of care provided, (2) the number provided and (3) the individual facility. The initial table is:

PND URGENT CARE SYSTEM

Type of Care	# of Occurences	Facility
Industrial Injury	62	Eastern
Non-Industrial Injury	59	Eastern
Infectious Disease	23	Eastern
Auto Accident	41	Eastern
Pre-Existing Condition	27	Eastern
Industrial Injury	89	Mustang
Non-Industrial Injury	66	Mustang
Infectious Disease	34	Mustang
Auto Accident	6	Mustang
Pre-Existing Condition	28	Mustang
Industrial Injury	11	Redwood
Non-Industrial Injury	55	Redwood
Infectious Disease	32	Redwood
Auto Accident	56	Redwood
Pre-Existing Condition	62	Redwood
Industrial Injury	19	Williams
Non-Industrial Injury	82	Williams
Infectious Disease	28	Williams
Auto Accident	84	Williams
Pre-Existing Condition	75	Williams
Industrial Injury	64	Blue Lion
Non-Industrial Injury	63	Blue Lion
Infectious Disease	29	Blue Lion
Auto Accident	21	Blue Lion
Pre-Existing Condition	20	Blue Lion

This original table provides the fundamental data required but it is difficult to discern any patterns within the fundamental data. A pivot table will be constructed to focus on the type of care provided by the overall system, with a breakdown per each facility. Once the pivot table dialog box was completed, the following pivot table is built:



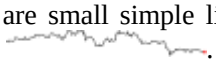
Row Labels	Sum of # of Occurences
Auto Accident	**208**
Blue Lion	21
Eastern	41
Mustang	6
Redwood	56
Williams	84
Industrial Injury	**245**
Blue Lion	64
Eastern	62
Mustang	89
Redwood	11
Williams	19
Infectious Disease	**146**
Blue Lion	29
Eastern	23
Mustang	34
Redwood	32
Williams	28
Non-Industrial Injury	**325**
Blue Lion	63
Eastern	59
Mustang	66
Redwood	55
Williams	82
Pre-Existing Condition	**212**
Blue Lion	20
Eastern	27
Mustang	28
Redwood	62
Williams	75
Grand Total	**1136**

Constructing the pivot table is straightforward as shown by the dialog box but one can draw conclusions that aren't easy to see in the initial table. We find that the most common type of care provided is "non-industrial injury" and a breakdown of the number of occurrences by facility. Critical thinking questioning can begin here: "Does our system have enough resources to adequately care for non-industrial injuries?" "Is the current mix of patient care optimized for this system?" There are many other potential questions to ask and the pivot table can be configured differently to study other issues. The larger the

dataset of fundamental data, the greater the utility of pivot tables. Pivot tables can be easily configured to provide insight not obvious from the raw data. Pivot tables can become essential tools of critical thinking.

This is just a single example of the use of "Pivot Tables" to stimulate critical thinking skills in your instruction, there are a host of other examples. Use your experience and subject matter expertise to build instructional modalities that most benefit your class. Your acumen in this academic topic will enhance the quality of your instruction and further develop the critical thinking skills in your students.

Sparklines

Sparklines are small simple line graphs that lack labels and scales. The following is an example of a sparkline:  . The benefit of Sparklines is that they can be directly inserted into text. Again, Sparklines are not sophisticated but they do give a quick but definitive idea of the trend of a data source. The Sparkline is constructed once the vector of data is cleansed and established as a contiguous row or column. The applications of Sparklines in healthcare, engineering, business and education are numerous.

Sparklines weren't introduced into Microsoft Excel until about 2008, well after my original paper was published. While Sparklines may seem unsophisticated, they are quick visuals that can be inserted into text that can complement and add emphasis. This type of integration can enhance critical thinking development because of their complementary nature. It can be somewhat cumbersome to connect written text to its corresponding graph. Sparklines can be used to see the trend in the data in a quick and easy fashion. Sparklines are not meant to replace informative and complex graphics, which Microsoft Excel can create with stunning precision and clarity. Effective tools don't have to be sophisticated. Sparklines have their role and can enhance critical thinking skills.

Probability and Statistics

Statistical software such as STATISTICA and TSP are state-of-the-art and are the tools for professional researchers. Statistical software have multiple strong functionalities but many are proprietary and expensive, which puts them out of the reach of many students. Student versions are available but the student may not use these statistical software in their careers.

Microsoft Excel has a "Data Analysis Add-In" with statistical functions that are powerful. The "Data Analysis Add-In" is robust enough to eventually use in their professional careers, which is a real advantage. The greatest advantage is that most students already possess Microsoft Excel so most students do not have to purchase additional statistical software. Also, students appreciate the opportunity to increase their acumen in Microsoft Excel. The "Data Analysis Add-In" is powerful so that this can be used as the statistical software in an introductory statistics course. The "Data Analysis Add-In" will automatically generate statistical diagnostics that are complete and insightful. The statistics textbook and "Data Analysis Add-In" are perfect complements in both introductory and intermediate statistics courses. Many introductory statistics textbooks are built around the "Data Analysis Add-In" as the statistical software for that textbook.

Regression analysis will be used on the following dataset where weight in kilograms is the independent variable and systolic blood pressure is the dependent variable. The objective is to determine if there is a statistical correlation between weight and systolic blood pressure (Fogler, 1981). The regression diagnostics from the "Data Analysis Add-In" follows:

Systolic BP	Weight (kg)
120	67
125	69
140	85
160	83
130	74
180	81
150	97
140	92
200	114
130	85

Example Data Set

Weight and Blood Pressure of n=10 individuals

Wt. (kg)	67	69	85	83	74	81	97	92	114	85
SBP (mmHg)	120	125	140	160	130	180	150	140	200	130

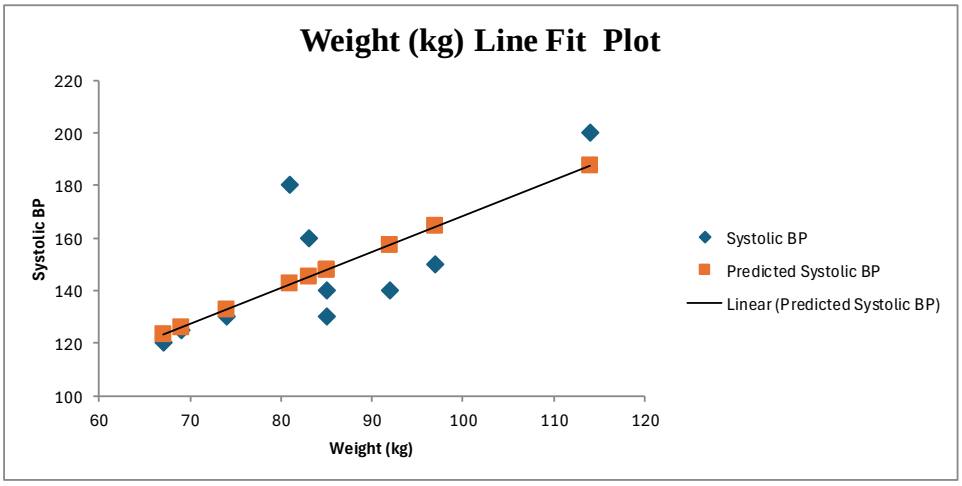
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7397936
R Square	0.5472946
Adjusted R S	0.4907064
Standard Err	18.368642
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	1	3263.244	3263.244	9.671536	0.0144475
Residual	8	2699.256	337.407		
Total	9	5962.5			

	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	31.973662	37.599214	0.8503811	0.4198348	-54.73028	118.67761	-54.73028	118.67761
Weight (kg)	1.3639473	0.4385811	3.1099093	0.0144475	0.3525776	2.3753171	0.3525776	2.3753171



The results from this linear regression are good but not exceptional – weight is a fair predictor of systolic blood pressure. Regression diagnostics were generated automatically by the "Data Analysis Add-In" and indicated that the independent variable is statistically significant. The "goodness-of-fit" test (R^2) is not as high as would be desired (Fogler, 1981). There were many more regression diagnostics such as ANOVA and correlation analysis that were generated that can provide insight into the statistical relationship between weight and systolic blood pressure and these can be studied as required.

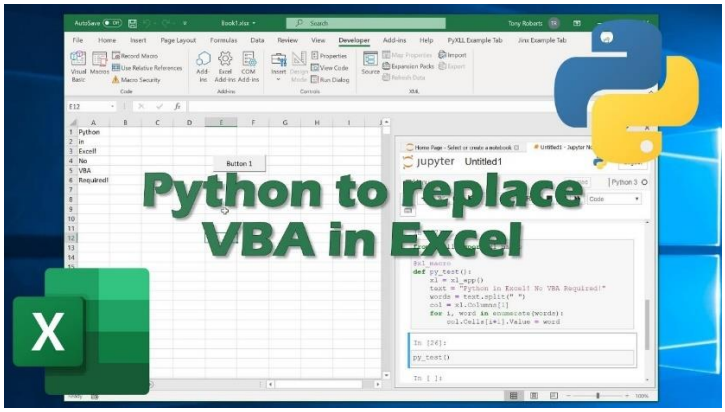
Critical thinking analysis should now begin. "Is the sample size too small?" "How difficult would it be to obtain additional data points?" "Should additional independent variables be added to this study, to make this a multiple regression?" There are many more questions to ask, such as the age of the people studied, gender, etc.

In addition to the regression diagnostics, the graph was automatically generated by the electronic spreadsheet. The original graph was modest initially, but it was a simple matter to add informative labels to the graph. This is another point in favor of the combination between critical thinking skills and

electronic spreadsheets. An important observation is that low weights and high weights do a good job of predicting systolic blood pressure but greater variability occurred with weights around the middle. These weights are around the mean but do not fit the regression line well. A closer examination of the data is warranted. In this instance, critical thinking skills are assisted by the built-in statistical functionality of the electronic spreadsheet.

Python

In 2023 Microsoft announced the ability to insert Python code into Excel. In the past, coding of procedures could be performed with "Macros" in Excel. There would be a long series of steps to perform and a "Macro" could be written to automate those steps. "Macros" are still available and remain a powerful tool, but users can code with Python now. Python is well-established in the software engineering environment and will probably become more popular than VBA in Excel.



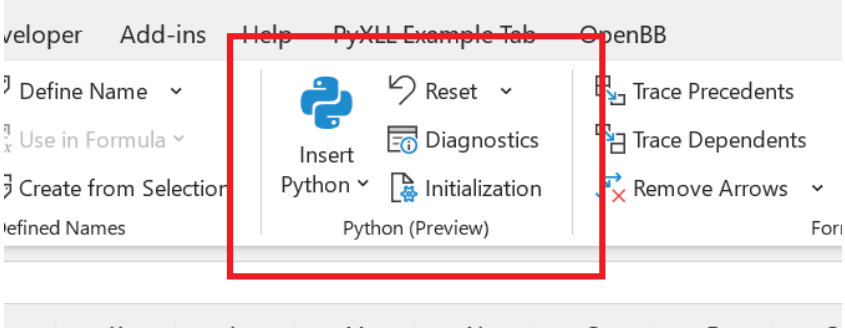
Here is some general information about Python: "Python is a general-purpose high-level computer programming language valued for its English-like syntax and powerful built-in data analysis and data science functions and libraries." (www.britannica.com, 2024) "Python is a high-level, general-purpose programming language known for its focus on code readability. Python is dynamically typed and includes a vast standard library, making it suitable for web development, scientific computing and more." (www.bing.com, 2024)

Python has extensive applications in healthcare analytics: "In the healthcare sector, data scientists use Python mainly to build machine learning algorithms and software applications for:

- Performing medical diagnostics
- Improving efficiency of hospital operations
- Genomic studies
- Drug discovery
- Predictive analytics

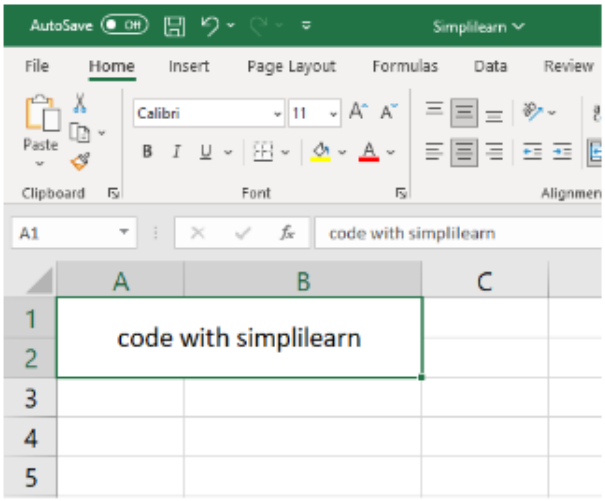
Such applications are essential to the health care sector: they process and analyze the data into understandable, meaningful, and reliable information for patients and health workers." (www.datacamp.com, 2024)

There is an icon in the Excel ribbon where the user accesses Python:



Here is an example of Python code in Excel:

```
from openpyxl.styles import Alignment
wb = Workbook()
ws = wb.active
ws.merge_cells('A1:B2')
cell = ws.cell(row =1, column = 1)
cell.value = 'code with simplilearn'
cell.alignment = Alignment(horizontal='center', vertical='center')
wb.save('C:/Users/SLP09375/Desktop/Simplilearn.xlsx')
```



The integration of Python and Excel introduces a powerful functionality in critical thinking skills. The combination of Python and Excel gives the user two of the most popular software applications available and will enhance the depth of critical thinking skills.

Conclusion

Students need to continuously improve and strengthen their critical thinking skills and electronic spreadsheets are excellent tools to implement to achieve this objective. This is not to imply that electronic spreadsheets are the only instrument available to support critical thinking because there are many other modalities available, including brainstorming with other individuals or back-of-the-envelope heuristics. The advantage is that electronic spreadsheets are widely accessible and can perform tedious mathematics quickly and accurately. Solutions and conclusions derived from critical thinking skills are best supported by quantitative analysis.

This paper presented just some of the functionalities that electronic spreadsheets can perform to enhance critical thinking skills. Not all of these tools are appropriate for each decision and finding the optimal combination of tools is more art than science. It can be a trial-and-error process to find the best mix of tools; however, the decision maker should be aware of the electronic spreadsheet tools available and use the appropriate tools to augment critical thinking skills. It's important to guide students to improve critical thinking skills. Use of a variety of teaching modalities is probably the best approach.

The potential support to critical thinking skills by an electronic spreadsheet is only limited by the innovativeness of the user. There is no single, definitive path that optimizes critical thinking skills in complex decisions but it is always a mistake to ignore and/or omit critical thinking. Encourage critical thinking skills in your students with the application of electronic spreadsheets whenever possible.

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