A Structured Approach to Teaching Fluid Power Systems Using Spreadsheets

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Abstract –The use of spreadsheets such as Microsoft Excel® to supplement Engineering Technology has been implemented in many areas with demonstrated success including fluid power systems. Spreadsheet based commercial products such as Fluid Tools® are available for quickly performing calculations required for component sizing and circuit analysis. However, a different approach was taken at Western Carolina University to supplement instruction and enhance student learning in a Fluid Power course. Students were required to develop independent Excel® worksheets in a logical progression corresponding to topics covered in class. These worksheets were then used by students to check homework problems and perform laboratory calculations. Further, a fluid power calculator was developed by each student through combining Excel® worksheets as a final semester long project. This paper will describe how this approach was implemented into a fluid power course at Western Carolina University. Background objectives will be presented along with descriptions and examples of student developed worksheets. Instructional methods, student performance, and educational merit will be discussed.

Keywords: Fluid power, circuit analysis, Microsoft Excel®

Background and Educational Objective

Engineering Technology programs typically focus on applied scientific knowledge and engineering principles while engineering programs emphasize the theoretical aspects.[1, 2] Modern computer tools have become an integral component of curriculum and provide efficient methods of blending theory into practice. However, this common use has also contributed to differences between the practicing engineer and technologist becoming more clouded.[3] Commercial software packages can enable students to rapidly perform calculations with relative ease and efficiency. Similarly, circuits can be created and simulated with only a modest knowledge of background theory. However, without adequate knowledge of fundamental laws and theory, this approach may give a false impression as to the ease of engineering design, component selection, and circuit analysis. This virtual approach does not always reflect characterization of actual circuit performance. Knowledge of basic laws and fundamental theory is essential for understanding fluid power systems.

Wingo suggested that effective course design strategies implement instructional methodologies that affect multiple dimensions of learning.[4] Students who prefer abstract conceptualization with concrete answers would likely benefit from solving theoretical problems in a more traditional manner as described by Kolb.[5] However, more positive learning outcomes may be achieved through active experimentation using a hands-on approach. Computer-based programs can be used to promote a better understanding of systems and component functions. Microsoft Excel® provides an excellent method of reinforcing learning through structured equations and provides a means for immediate feedback as suggested by Marsh[6]. Graphing and charting functions can also reinforce the basic understanding of systems through visual feedback. A more structured approach for teaching fluid power at Western Carolina University was implemented employing some of these approaches. However, students were required to develop accompanying worksheets using Microsoft Excel® corresponding to theoretical topics presented in class. The primary objectives of this approach were to reinforce theory through interactive formula based learning

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activities and to develop working tools for evaluating fluid power systems. As opposed to using commercial software products, students were required to write equations and structure worksheets through a logical interactive approach. Individual worksheets were assembled as a working group of system tools, in the form of a final semester project.

THEORETICAL FOUNDATIONS

Traditionally engineering technology courses in fluid power have followed a classical approach by covering basic fundamentals and theoretical laws. The Fluid Power course at Western Carolina University follows a similar approach with emphasis on traditional theory and logical sequence as shown below:

Logical Sequence and Course Content	
Fluid Properties	Actuators
Pascal's Law	Pressure losses and circuit analysis
Continuity Equation	Fluid, Brake, and Torque Horsepower
Bernoulli's Equation	Pumps and Efficiencies
Reynolds' Numbers	Perfect Gas Laws
Darcy's and Hagen-Poiseuille equations	Pneumatic systems

Table 1: Course Sequence and Content

While commercial software packages are available for providing relatively quick calculations to analyze variables and determine logical parameters for system components, students may benefit more from developing structured equations based on presented theory. Formulas entered in spreadsheet format require students to have a better grasp of variables and relationships. Further, calculations performed in both U.S. Customary and SI units can be accommodated with relative ease by using spreadsheets.

STRUCTURE AND APPROACH

After theoretical relationships were covered in class and reviewed in the Esposito[7] textbook, students began developing corresponding Excel® worksheets for use in homework and laboratory assignments. Students were required to develop and submit completed worksheets each week as evidence of demonstrated competency of the topic covered. Further, students were encouraged to use developed worksheets to validate manual calculations from both homework and laboratory assignments. This logical approach was taken throughout the duration of the semester, and progressed from basic to more advanced topics. Examples of student generated worksheets showing relevant formulas as entered in Excel® are described in the following section.

Fluid Properties and Pascal's Law

Corresponding to the first two topics presented in class lectures, students began by developing worksheets for fluid properties and sizing hydraulic cylinders based on Pascal's law as shown in Figures 1 and 2. Both theoretical formulas and graphical representation were encouraged, and calculations in the U.S. customary and S.I. units were required.

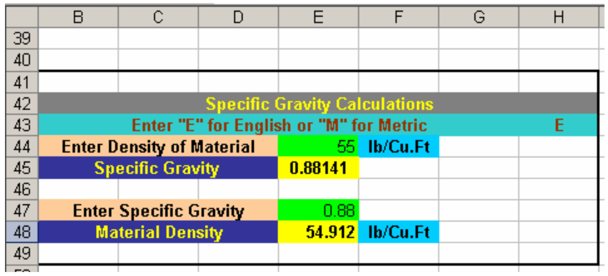

Figure 1: Fluid Properties Module

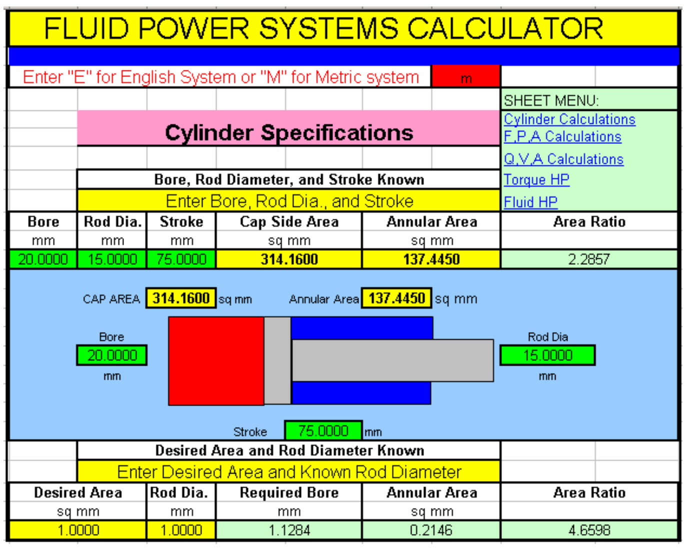

Figure 2: Cylinder Specifications Module

Efficiency and Power

Theoretical relationships of power, horsepower, and efficiencies were presented to students as shown in Figure 3 and Table 1. Sample problems were worked in class coupled with assigned homework problems requiring hand calculations which were checked prior to the development of the actual Excel® worksheet.

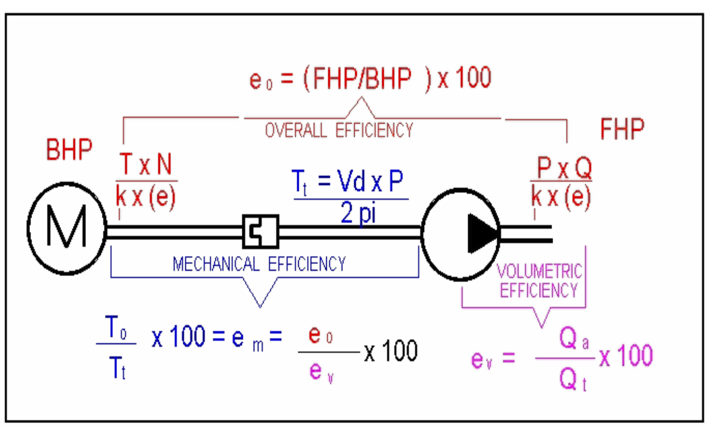

Figure 3: Theoretical Relationship between Horsepower and Efficiency

Nomenclature

BHP - *Brake Horsepower*	N – *RPM*	K – *Conversion constant*
FHP - *Fluid Horsepower*	P – *Pressure*	T_o – *Observed torque*
T – *Torque*	Q – *Flow rate*	*Tt – Theoretical torque*
E_m – *Mechanical efficiency*	e_v – *Volumetric Efficiency*	e_o – *Overall efficiency*
V_d – *Volumetric displacement*		

Table 2: Nomenclature Related to Horsepower and Efficiency

After demonstrating a theoretical understanding of horsepower and efficiency, students were required to develop the next logical worksheets. Using Excel, students developed related worksheets for calculating flow rate, pressure, horsepower and efficiency. By observing changes in one variable, students were able to obtain immediate feedback of how such changes related to theoretical relationships, and thereby were able to gain a better understanding over the conventional manual calculation approach. Examples of student generated worksheets for horsepower and efficiency are show in Figures 4 and 5.

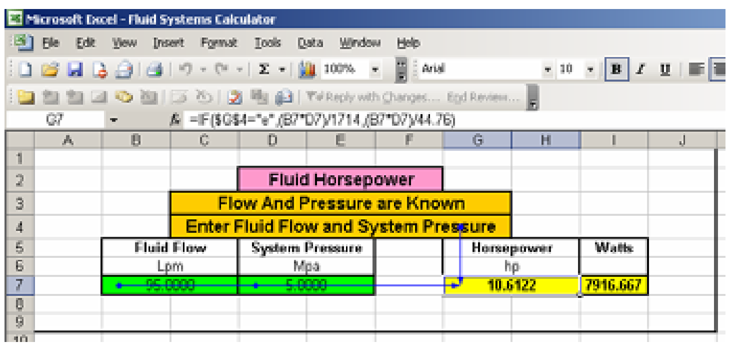

Figure 4: Partial Fluid Horsepower Worksheet

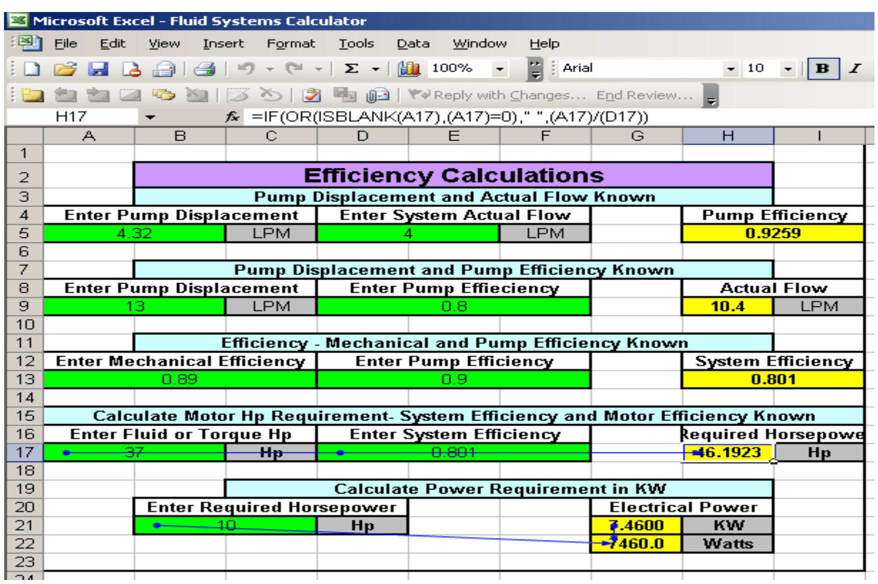

Figure 5: Partial Pump Efficiency and Power Module

The logical approach and sequence as described previously was incorporated throughout the semester leading up to circuit analysis. Engineering technology students typically have more difficulty with Bernoulli's equation and the theory behind circuit analysis. In an attempt to facilitate a better understanding of the topic, a practical approach was taken by evaluating system requirements for a single actuator hydraulic press.

Students were required to size conductors, determine pressure drops, and conduct circuit analysis through both manual and spreadsheet calculations. While conductor sizing and pressure drop analysis can be carried out through manual calculations, the time involved to perform such calculations can be tedious and further lead to confusion on the part of the student. However, spreadsheets provide immediate feedback allowing students to more quickly grasp the effect of changing critical variables in the equation. A simplified schematic of the hydraulic press circuit presented to students for analysis is shown below.

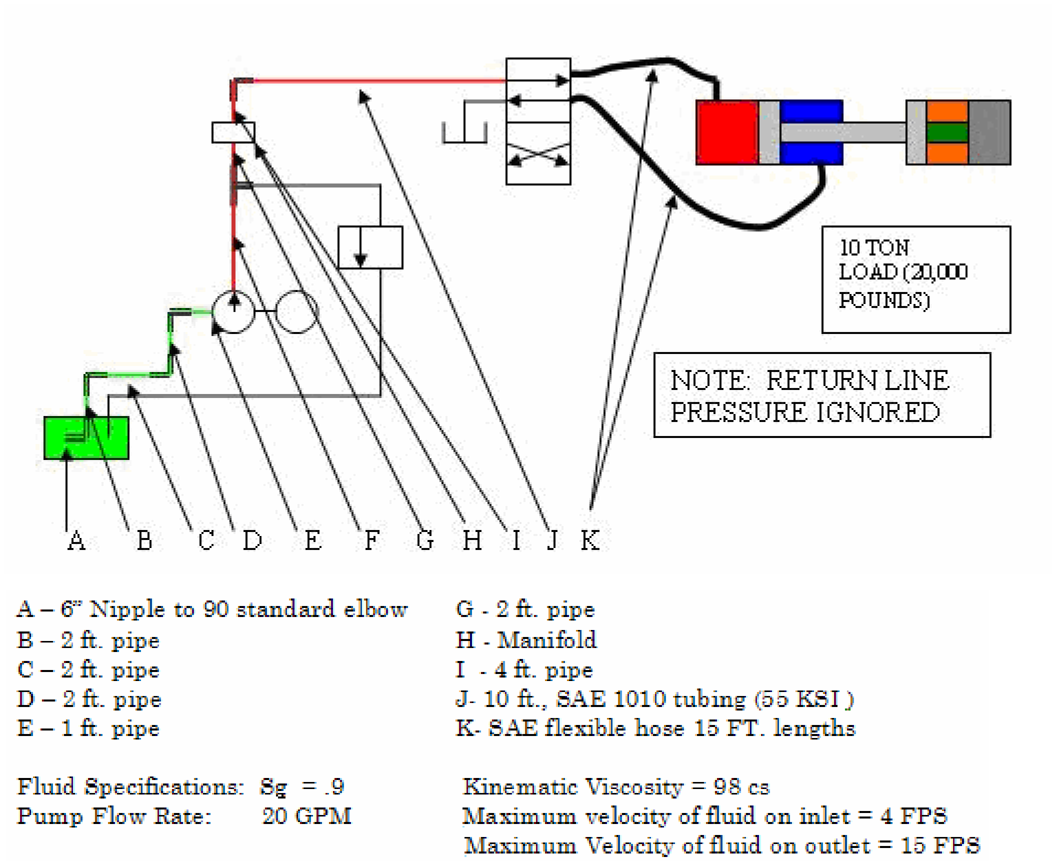

Figure 6: Example Problem for Conductor Sizing and Pressure Drops

The previous system analysis problem as presented during lecture focused on specifying acceptable fluid conductors and determining pressure losses through selected conductors at critical locations within the circuit. Students were required to perform hand calculations prior to constructing an associated Excel® worksheet. For illustration purposes, an example of logical steps and theoretical calculations are shown for head loss due to friction relative to the hydraulic press circuit. A student developed Excel® worksheet based on the following equations and as presented by Esposito[7] is shown in Figure 8.

Students were presented design parameters and known specifications along with recommended logical steps in determining acceptable conductor sizes and solving for pressure losses due to friction. Fluid velocity on the inlet side of the pump (20 gallons per minute flow rate) was specified as a maximum of 4 feet per second. Similarly, the outlet velocity was limited to 15 feet per second. Steps in solving for the appropriate conductor and associated pressure loss due to friction included the following:

1. Determine the theoretical Inside Diameter (I.D.) for the required conductor
2. Specify the acceptable standard size conductor available
3. Calculate the fluid velocity and kinetic energy for conductor specified
4. Calculate Reynolds Number (NR) and associated friction factor (f)
5. Determine head loss due to friction based on friction factor, length; including conductor length and equivalent length of valves and fittings, conductor diameter, and kinetic energy
6. Determine pressure loss within the section of interest.

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1. THEORETICAL I.D. FOR CONDUCTORS: $D = \sqrt{.408(Q)/V}$

INLET | ***OUTLET***

$D = \sqrt{(.408(20))/4} = 1.428in$ | $D = \sqrt{(.408(20))/15} = .737in.$

SYSTEM PRESSURE: P = F/A = 20,000 lbs./12.57 in^2. = 1591 psi

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2. PIPING INLET: USE 1 ½ SCHEDULE 40; I.D. 1.610 in.

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3. V= .408(20)/ 1.61^2 = 3.148 ft./sec. $v^2/2g$ = .154 ft.

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4. NR = [(7740)(3.148)(1.61)]/ 98 = 400 (laminar)

f=64/400 = .16

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5. $H_L = f(\frac{L}{D})(\frac{v^2}{2g})$

L = Lpipe + Le

Lpipe = .5+2+2+2+1 = 7.5 ft.

$Le = (\frac{\sum K}{f})(D/12)$ (Note: D is divided by 12 to convert to feet)

$Le = (\frac{3.6}{.16})(1.61/12)$ = 3.02 ft

Le = 7.5 + 3.02 = 10.52 ft

$H_L = .16(\frac{10.5}{.134})(.154)$ = 1.93 ft. (Note: D is divided by 12 to convert to feet)

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6. $\Delta P = \gamma h$ in this case, h = H_L Therefore: 56.16 lbs/ft^3 (1.93 ft) = 108.38 lbs/ft^2

ΔP= 108.38 lbs/ft^2 X 1 ft^2/144 in^2 = **.7527 psi** (negative on inlet side of pump)

Figure 7: Example Hand Calculations Showing Pressure Drop on Inlet Side of Pump

FLUID SYSTEMS CALCULATOR: PRESSURE LOSS MODULE

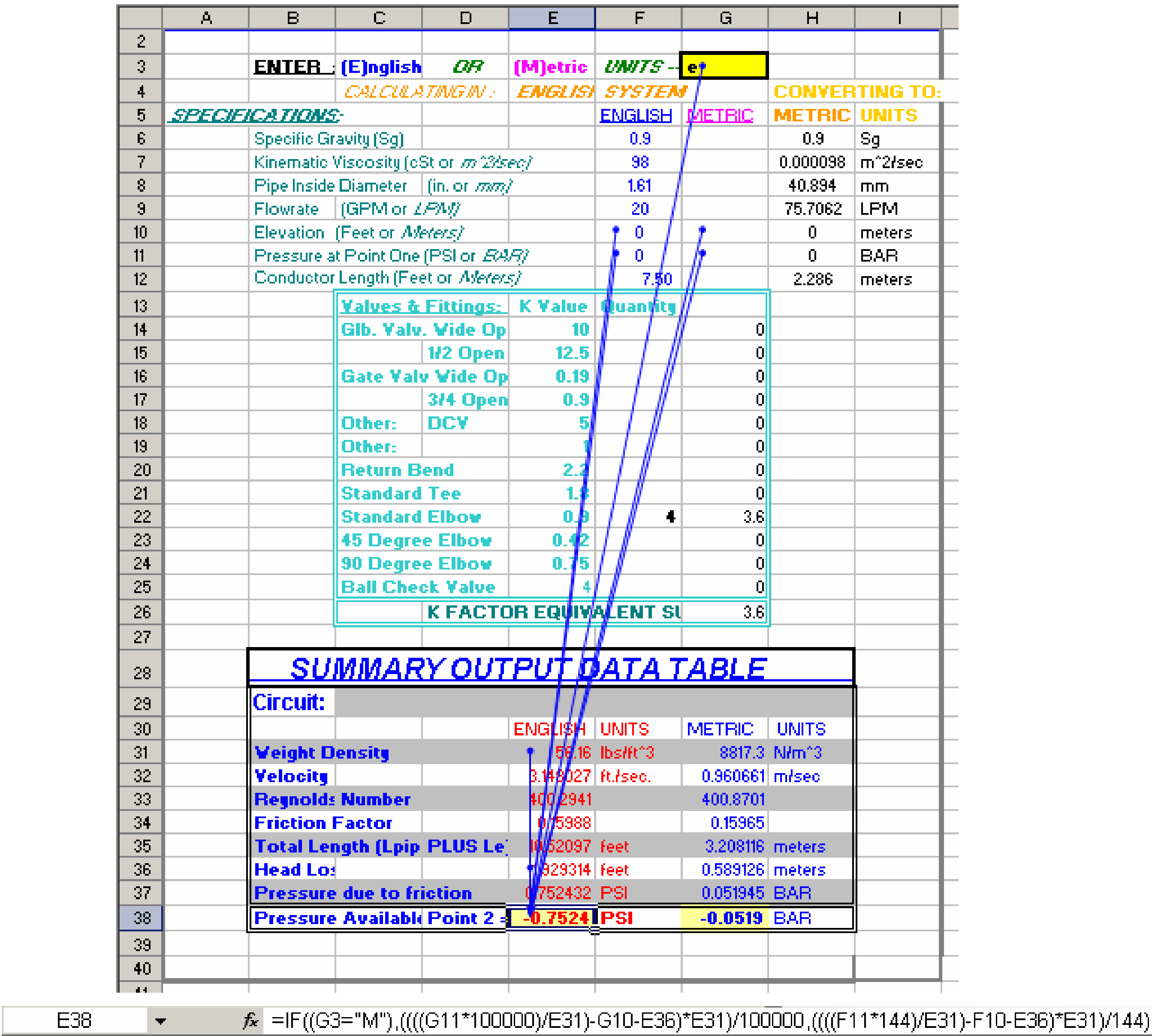

Figure 8: Pressure Loss Worksheet Showing Formula Entry and Associated Reference Cells.

EDUCATIONAL MERIT

The approach taken in using spreadsheets to enhance teaching and learning provides a solid method for supplementing instruction in fluid power. Enhanced learning is evidenced through reinforcing computer skills and strengthening applications in verifying engineering design parameters related to fluid power systems. However, these skills are not always explicitly taught in engineering curriculums where the focus has been on content and analytical skills of specific engineering disciplines. Industry and the Accreditation Board for Engineering and Technology (ABET) nonetheless expect engineering graduates to have well developed computer skills.[8] The modular approach implemented at Western Carolina University provides a logical and systematic method for building on theory and developing essential computer skills. Through immediate feedback, students can gain a better understanding of variables in equations and the impact of changing design parameters in a system.

SUMMARY AND CONCLUSIONS

Student feedback and performance has been positive, and integrating worksheets into a semester project provided a vehicle for transferring theoretical knowledge to practical, systematic application. Compared to previous semesters when students performed only manual calculations, an improvement was observed in students' ability to more rapidly understand theoretical concepts. Overall, students also performed better on homework assignments, laboratory assignments, and tests compared to previous semesters when the use of spreadsheets was not integrated into the course. This practical approach has also resulted in improved skills that can be directly applied in other classes and also has provided more continuity within the Engineering Technology curriculum at Western Carolina University. Future assessment will include a planned experimental design for comparing two groups to determine if the observed differences are statically significant. Ongoing program assessment will continue to provide feedback on the effectiveness of supplementing instruction using methods presented in this paper.

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