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Integrated Learning In Context for Heat Exchanger Analysis

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Abstract

An Engineering Technology program is developing a new vertically integrated undergraduate energy systems curriculum that crosses traditional course boundaries. The goal is for students to recognize and understand energy conversion in a more comprehensive way by showing how similar processes occur in different disciplines. Courses in thermodynamics, electrical power generation, fluid power, manufacturing processes, and internal combustion engines are all being modified to include modules on energy conversion as a unifying and integrating theme. This paper targets one module of this comprehensive multi-course re-design, where a two-week segment of an introductory thermodynamics course was re-imagined to present the overarching energy conversion topic in an integrated learning-in-context format, so that the learning occurred just in time and the learning outcomes were tied to a practical hands-on experience to evaluate a heat exchanger. A survey to assess student learning showed that students 1) were more confident in their technical knowledge after having completed this project and 2) preferred to have detailed instructions to complete lab procedure (as opposed to working on their own).

Energy Transformation

Higher education has been going through a transformation of teaching in many disciplines [1] – [7]. The transformation helps recognize our interconnectedness with others [1], and that the instructor must strike a careful balance between support and challenge [2]. Instructors are expected to facilitate students' active engagement in developing knowledge and skills [3]. There is a social aspect in this process [4], as well as an evolution of institutional environment toward supporting student learning [5]. Transformation involves deep changes, including the curriculum structure, toward the same goal [6]. For universities, it is an opportunity but becomes real only when perceived by actors [7]. For employers, who are seeking college graduates that have the ability to not only apply technical expertise, but also to work with new information, collaborate, innovate and solve open-ended problems, college transformation is a welcome trend, and that is the motivation behind an energy transformation project underway in an undergraduate Engineering Technology program. The goal is a new energy systems curriculum that crosses traditional course boundaries to teach students that similar energy conversion processes occur in many different disciplines.

Figure 1 shows that the courses in the energy system curriculum appear in a progression, from introductory first year courses to career-related courses taken by graduating seniors (4th year). The unifying and integrating theme, whether 1st year materials or 3rd year thermodynamics, is modules highlighting basic energy conversion processes. Another aspect of Figure 1 is an effort to maintain continuity between the energy conversion modules in different courses by creating an Energy Certificate. Students will earn a badge for successfully completing each course-based energy conversion module. By completing a number of badges, plus an energy-related professional experience in HVAC, Utilities, Transportation, or Manufacturing, students can also earn an Energy Certificate that will appear on their transcript. This is intended as an entry-level credential that could help launch a student's professional career in one of the targeted industries.

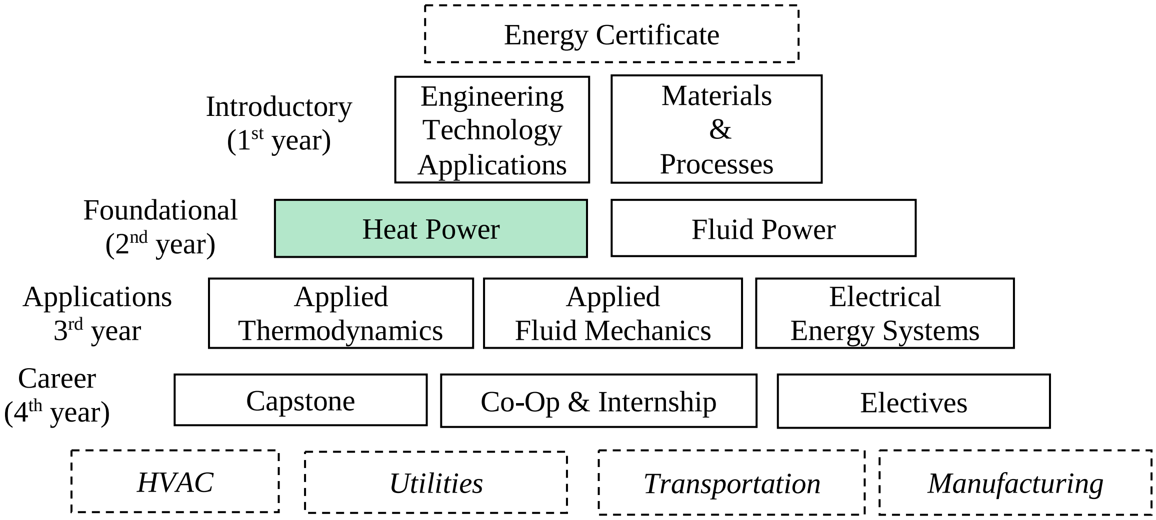
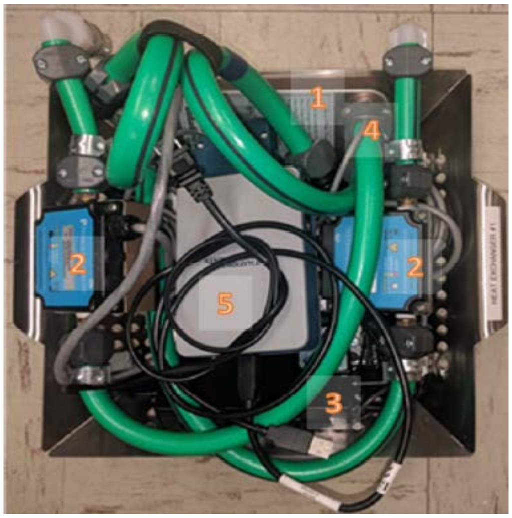


Figure 1. Energy conversion modules are being integrated into the 4-year plan of study.

Integrated Learning In Context

The green highlighted box in Figure 1 identifies a sophomore-level lab-based thermodynamics course that has been re-designed so that students work in small groups on open-ended projects that span multiple weeks and multiple technical topics. The goal is to give students enough time to explore and work on their own, helping them gain a deeper understanding of the technical material. Beyond basic thermodynamics and heat transfer, students are getting experience with data acquisition equipment, including troubleshooting. A lab project that does not go smoothly can have the most beneficial impact on students because they learn to question the accuracy and integrity of the data being collected. The ability to question and correct lab results does not always happen in more process-oriented experiments that are completed in one week of lab time. Figure 2 shows a small but sophisticated industrial heat exchanger (HX) test apparatus that was developed so students can evaluate energy conversions related to heat transfer.



1. Brazed Plate Heat Exchanger
2. Flow Meters (Hot & Cold)
3. Power Supply
4. IC Temperature Sensor (1 of 4)
5. USB Data Acquisition Module

Figure 2. Heat exchanger test apparatus for energy conversion investigation.

Heat Exchanger Apparatus

Figure 2 shows that the apparatus has a relatively compact 1 ft^2 cross section for easy storage while not in use. The numbered elements on the Figure highlight the key components. A small brazed plate heat exchanger (1) [8] has flow meters (2) connected to the hot and cold sides. A total of four integrated circuit temperature sensors (4) are used to measure the temperature differential for both the hot and cold sides. All sensors are connected to a USB data acquisition module from National Instruments.

The heat exchanger apparatus has a number of subtle features based on experiences with this equipment over time. The entire device is mounted inside a perforated stainless steel pan that fits over the edge of a laboratory sink, see Figure 3, to contain any inadvertent leaks that occur. In addition, the HX apparatus has hose connections that quickly connect to the hot & cold water fixtures in a laboratory sink. Those same connections adapt to a nearby compressed air line so excess water can be purged from the apparatus before it is stored, because previous experience has shown that stagnant water will damage the rotating wheel on the flow meters over time.

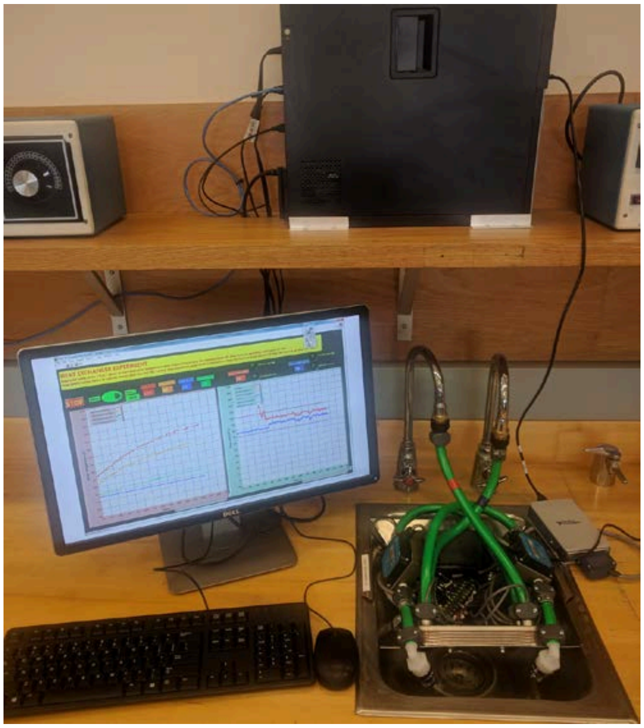


Figure 3. Heat exchanger test apparatus connected to hot and cold water and computer monitor displaying current data along with graph of temperature and flow versus time.

In order to provide an easy access to all the electrical signals in the HX test apparatus, a terminal box was used to connect the electrical wires, shown in Figure 4. The terminal box has a removable clear cover. Each wire has been labeled for identification purposes. Each of the four temperature sensors has been securely mounted inside of a hose clamp on the ½ inch barbed fitting of the heat exchanger.

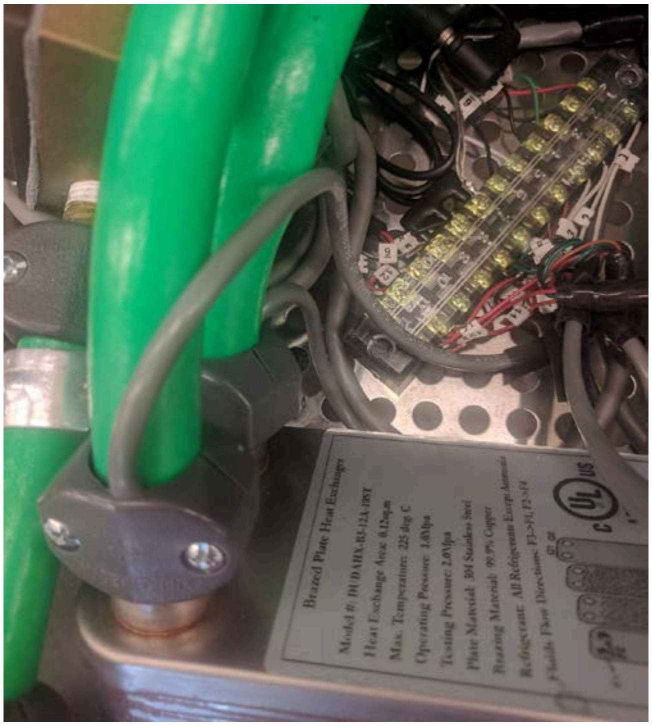


Figure 4. The electrical wiring of the heat exchanger test apparatus has been designed for easy identification and access for troubleshooting.

One small but useful design solution is an aerator on the return fitting from the heat exchanger. Visible in Figure 5. The aerator prevents water splashing during the test run as when water is collected to calibrate the flowmeters.

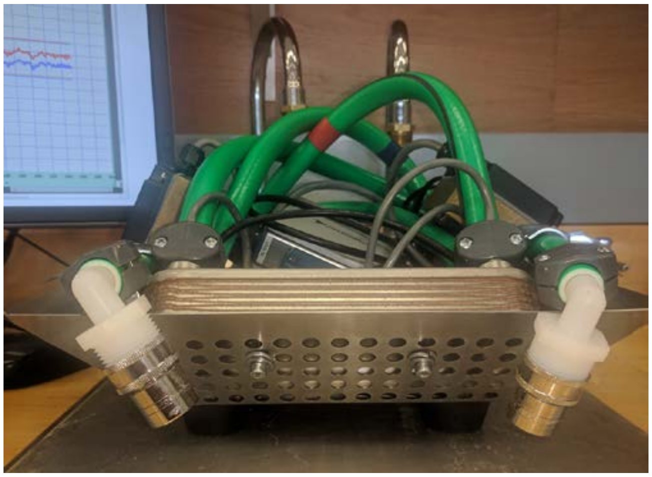


Figure 5. The water drains of the heat exchanger test apparatus feature aerators to prevent water splash in the sink.

Another useful design solution is the mount of the flowmeters. Two brackets hold both water hoses connected to the flowmeter, see Figure 6. The hose mounts allow for the rotation of the flowmeter to access the rotor which is visible through a clear back plate.

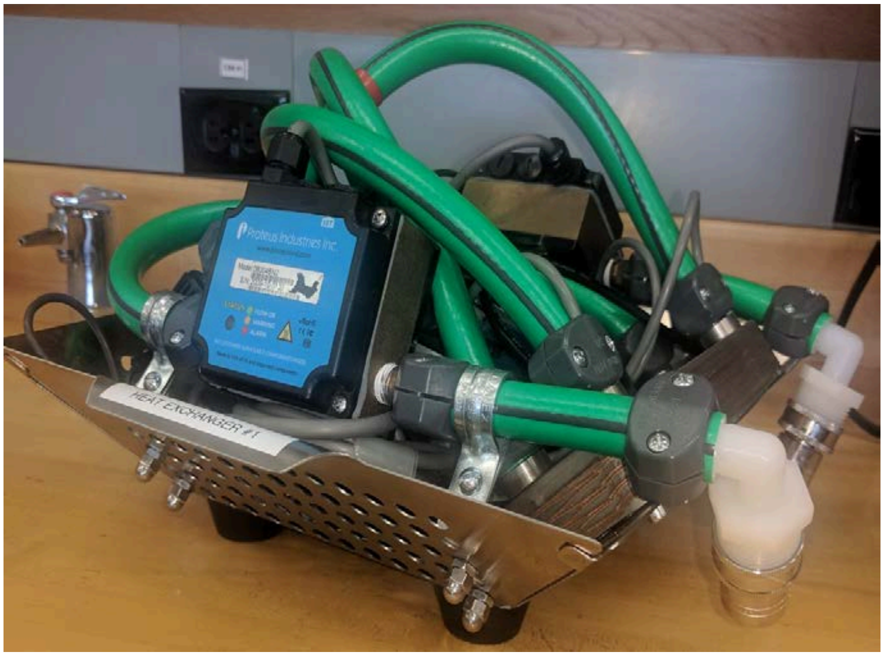


Figure 6. Both flowmeters of the heat exchanger test apparatus can be rotated along a horizontal axis to access their back sides for troubleshooting.

The HX test apparatus has six output signals: four for water temperature, and two for water flow rate. An USB data acquisition voltage module 9201 made by National Instruments was used as hardware. The software program was written using LabVIEW 2016. The Front Panel of the HX program is shown in Figure 7. On top of the screen there are digital displays of the four temperatures and two of the flow rates. For water flow rates, there are two LED warning light that help maintain water flow within a suggested range.

The bottom left graph of Figure 7 is for displaying four water temperatures over the time of the test run. Both the temperature graph and the digital displays help the students to follow the experiment and decide when to stop it when the water temperature stabilizes. The water supply is at around 60 °F for cold water and 115 °F for hot water. The heat exchanger produced temperature drop of around 20 °F for hot water and around 15 °F for cold water. It took 50 to 60 minutes for all four temperatures to settle on their final values. The water flow rates are drawn on the graph to the right. This graph displays the four flow-rate limits so it is easy for the students to adjust the faucets, as well to have a monitoring tool that allows to spot larger changes to the flow rates.

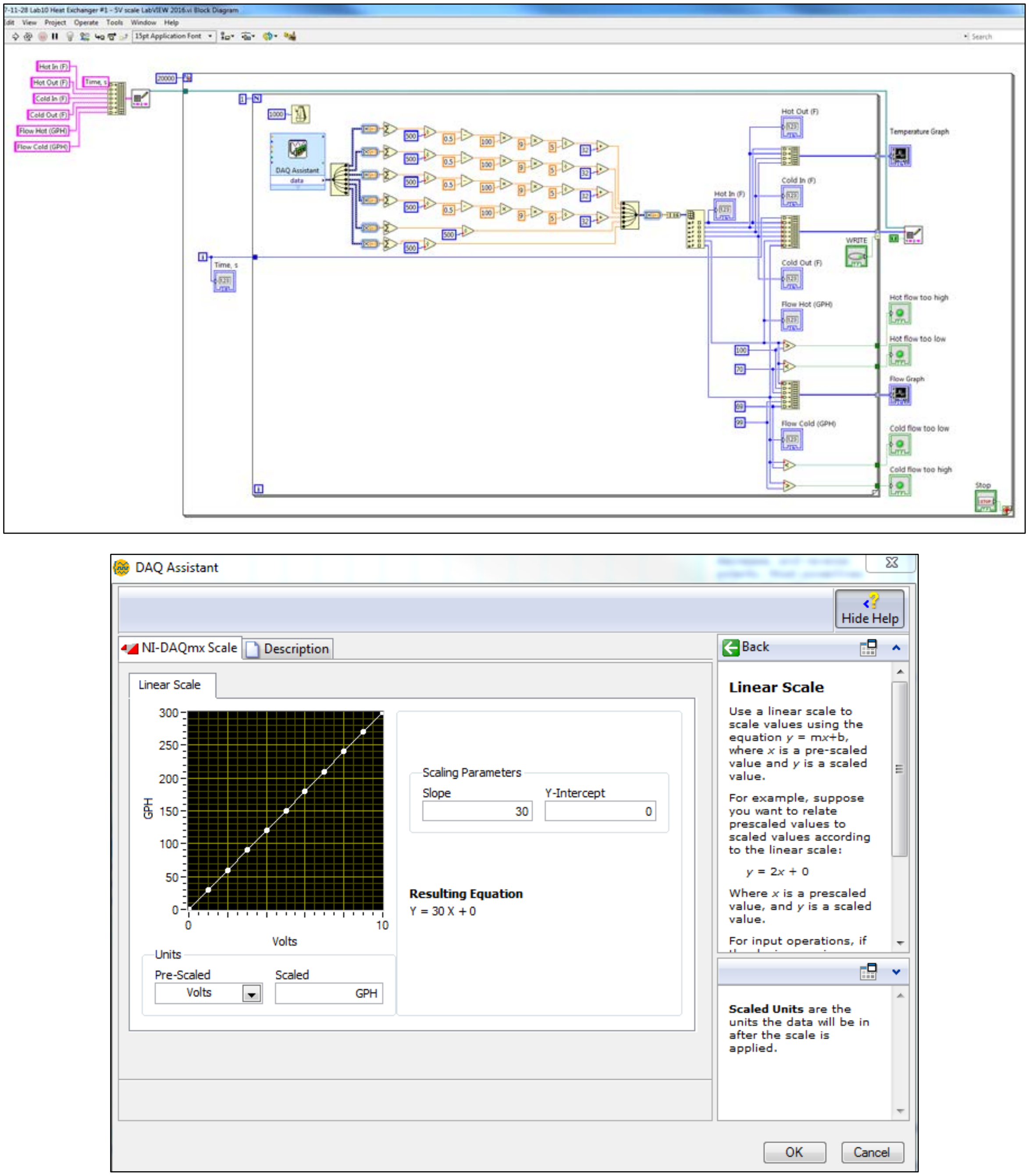
Press solid white arrow ("Run") above to start displaying temperature data. Adjust flow to keep the warning lights off. Flow does not accurately read below 15 GPH.
Press WRITE button below to add the current data to a text file. To stop data acquisition, press STOP button below. Open the file from Excel (select "All Files" for Excel to see your text file).

Time, s: 535
Hot In (F): 102
Hot Out (F): 88
Cold In (F): 73
Cold Out (F): 91
Flow Hot (GPH): 73
Flow Cold (GPH): 72

HEAT EXCHANGER #1 Test on 10/18/2017:								
Time, s	Hot In (°F)	Hot Out (°F)	Cold In (°F)	Cold Out (°F)	Flow Hot (GPH)	Flow Cold (GPH)	Hot Diff. (°F)	Cold Diff. (°F)
14	73	72	71	70	1	1	1	1
267	77	75	72	75	76	72	2	-3
279	80	77	71	78	76	74	3	-7
308	87	81	71	82	75	74	6	-11
333	90	81	70	83	71	75	9	-13
371	93	83	72	86	88	73	10	-14
381	95	84	71	87	82	72	11	-16
451	100	86	72	89	75	72	14	-17
460	99	87	72	89	78	72	12	-17
478	100	87	72	90	79	72	13	-18
532	102	87	72	91	72	72	15	-19

Figure 7. LabVIEW Front Panel of the heat exchanger test apparatus during the run with sample data written to a file shown after the run.

The Block Diagram of the LabVIEW program is shown in Figure 8. Students have access to edit it to learn how the DAQ system works. They enter the calibration curves for the flowmeters after they run the calibration test and calculate the parameters of the curve. They do that by opening the DAQ Assistant and entering the slope and intersection of the calibration line, as shown below.



Units

Pre-Scaled: Volts

Scaled: GPH

Scaling Parameters

Slope: 30

Y-Intercept: 0

Resulting Equation

Y = 30 X + 0

Linear Scale

Use a linear scale to scale values using the equation *y* = m*x*+b, where *x* is a pre-scaled value and *y* is a scaled value.

For example, suppose you want to relate prescaled values to scaled values according to the linear scale:

y = 2*x* + 0

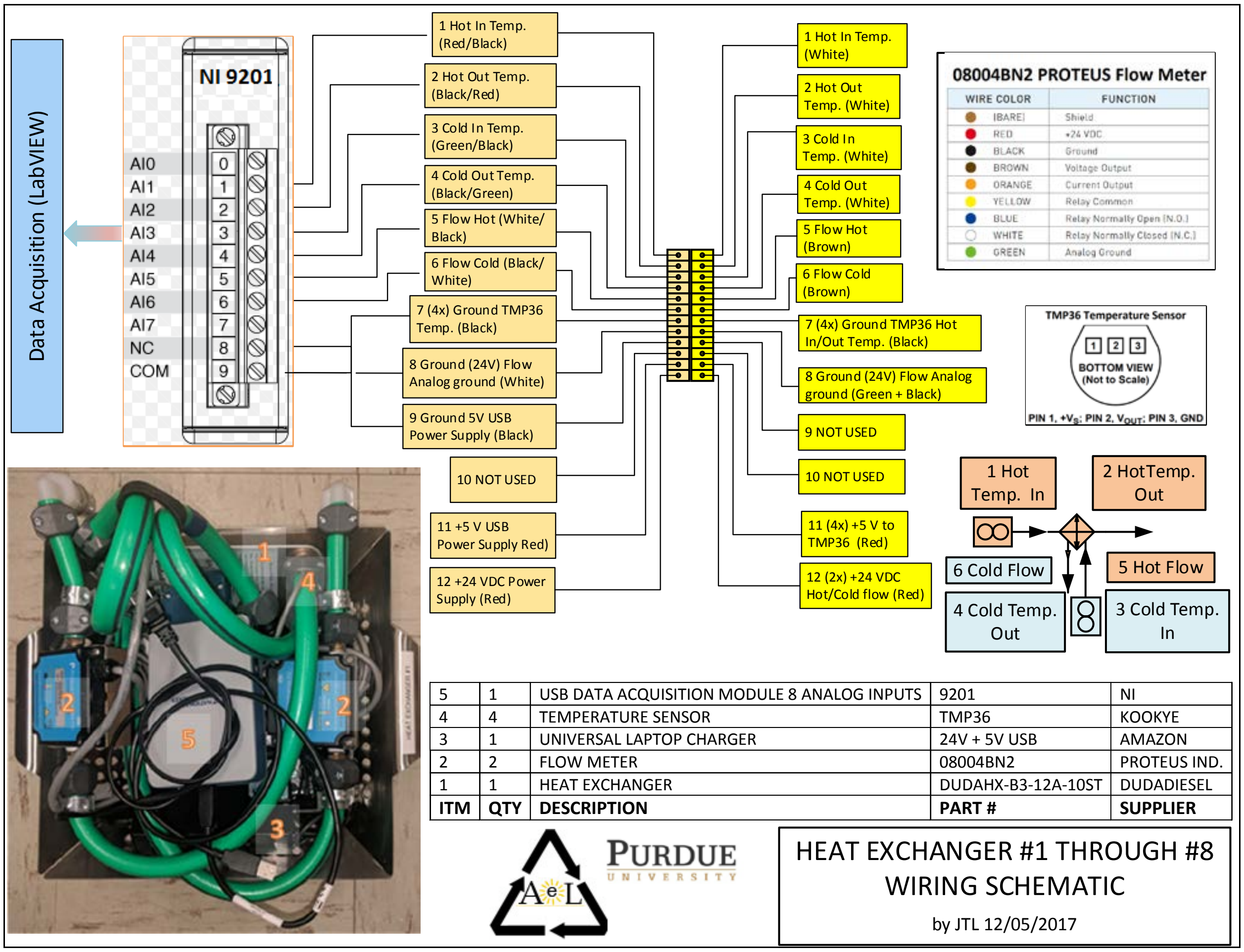
Where *x* is a prescaled value, and *y* is a scaled value.

For input operations, if

Scaled Units are the units the data will be in after the scale is applied.

Figure 8. LabVIEW Block Diagram of the heat exchanger test apparatus and the calibration curve for one flow meter.

Last, but not least, a wiring schematic is provided as shown in Figure 9 to the students to familiarize themselves with the overall design of the HX test apparatus. It would be too hard for the students to understand how the data flow occurs with only two two-hour lab periods dedicated to conduct the whole HX test.



08004BN2 PROTEUS Flow Meter

WIRE COLOR	FUNCTION
[BARE]	Shield
RED	+24 VDC
BLACK	Ground
BROWN	Voltage Output
ORANGE	Current Output
YELLOW	Relay Common
BLUE	Relay Normally Open [N.O.]
WHITE	Relay Normally Closed [N.C.]
GREEN	Analog Ground

ITM	QTY	DESCRIPTION	PART #	SUPPLIER
5	1	USB DATA ACQUISITION MODULE 8 ANALOG INPUTS	9201	NI
4	4	TEMPERATURE SENSOR	TMP36	KOOKYE
3	1	UNIVERSAL LAPTOP CHARGER	24V + 5V USB	AMAZON
2	2	FLOW METER	08004BN2	PROTEUS IND.
1	1	HEAT EXCHANGER	DUDAHX-B3-12A-10ST	DUDADIESEL

HEAT EXCHANGER #1 THROUGH #8
WIRING SCHEMATIC
by JTL 12/05/2017

Figure 9. Wiring schematic of the heat exchanger test apparatus.

Heat Exchanger Project

The heat exchanger project is delivered as a multi-week session at the end of the semester. It is more inquiry-based and less about conducting a formal laboratory experiment. The experience has been consciously set up so that students can work at their own pace and achieve a variety of results. When students have questions or problems, they access technical information for sensors, wiring, and plumbing so they can determine the solution on their own.

In the first week's session, students explore how data acquisition (DAQ) works, including hardware, software, and troubleshooting. Students develop their own protocol for calibrating the sensors to find the linear relationship between the physical quantity being measured and the voltage output of the sensor. In other words, students execute measurements to establish the relationship between flow in gph (gallons per hour) and the voltage output of the sensors. Along the way, students may need to identify and resolve open-ended issues with everything from loose sensor wires to troublesome software. The troubleshooting experience is one of the more valuable lessons from this heat exchanger project.

In the second heat exchanger, laboratory session students acquire data and conduct a thermodynamic / heat transfer analysis to assess the heat transfer from hot side to cold side. The first equation for assessing sensible energy transfer is shown in equation 1. This is a commonly used equation for computing the rate of heat transfer ($\dot{Q}$) based on mass flow ($\dot{m}$), specific heat (c_p), and temperature differential $(T_{out} - T_{in})$:

$$\dot{Q} = \dot{m} c_p (T_{out} - T_{in}) \tag{1}$$

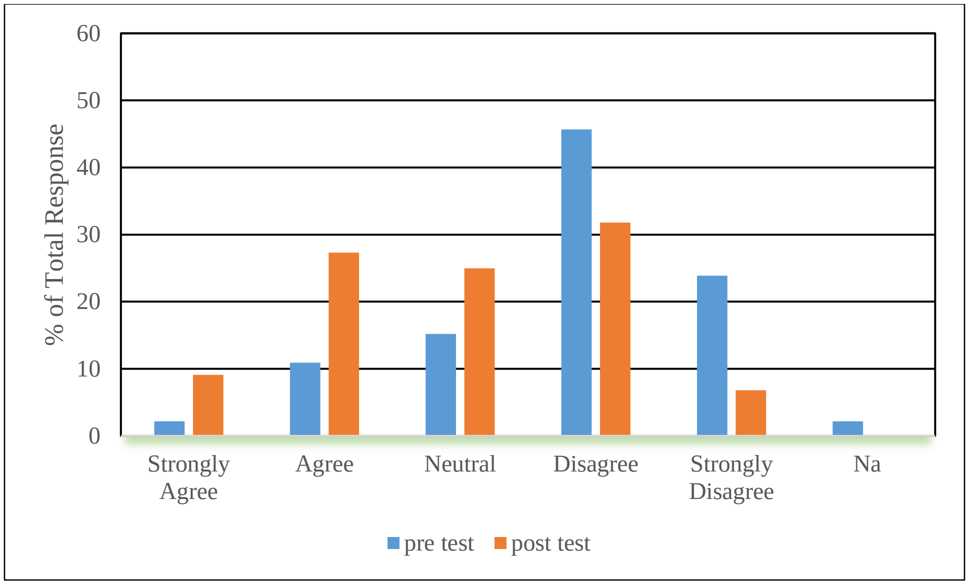
Recall that an Energy Conversion theme is the guiding principle for all the energy modules being developed in multiple courses. In this heat exchanger project, the energy conversion concept is demonstrated based on an established equation for heat exchanger effectiveness (ε) that is shown in equation 2. Effectiveness is comparable to efficiency because it computes heat transfer as compared to the maximum potential for heat transfer. The subscripts "H" and "C" in equation 2 refer to the hot and cold side of the heat exchanger. An effectiveness of 100% represents perfect heat transfer. Anything less than that indicates opportunities to improve heat transfer performance.

$$\varepsilon = \frac{\dot{Q}_{net}}{C_{min}(T_{H,in} - T_{C,in})} \tag{2}$$

Evaluation of Student Learning

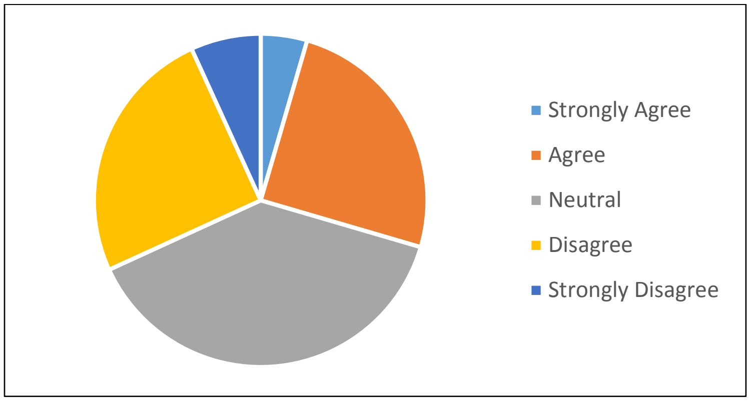
Two on-line surveys were conducted to assess student reaction to the new learning in context format, where students had more freedom to complete the project at their own pace. In contrast to more traditional experiments in this class, students were given broad guidelines and general equations, but decisions about the experimental setup and data collection were left up to the student teams. The first survey was conducted before the laboratory project started and the second was conducted after the project was completed. Both surveys were mandatory, so 100% participation by the 45 students in the class was achieved.

Graph 1 shows the responses for both pre and post tests for the survey question about "experience troubleshooting heat exchangers". It was encouraging to see the improvement from pre to post test. Prior to this heat exchanger project, only 13% of all students "agreed" or "strongly agreed" that they had this experience. After the heat exchanger project, 36% of all students "agreed" or "strongly agreed" with this statement. This is taken as evidence that completing the small amount of plumbing and data acquisition work for this project was beneficial to students and gave them confidence in a new technical endeavor.



Graph 1. Responses to “I have experience troubleshooting heat exchangers”.

The results of the pie chart in Graph 2 showed a result that should probably not have been surprising. Students were not all that enthused about being given more freedom to complete this project on their own. The project would have been easier and quicker if a more detailed step-by-step set of instructions had been provided. Less than 1/3 of the students preferred the open-ended format, about 1/3 were neutral, and 1/3 did not like this approach. The student responses to this survey question do not necessarily mean that open inquiry is a bad thing, but it is a reminder that this type of laboratory project should be pursued with caution. Not all students have the confidence or ability to work on their own.



Graph 2. Responses to “I prefer to have control over the procedure for completing a laboratory project (as opposed to being given a detailed set of instructions)”.

Conclusions

A new Energy Certificate being developed for an Engineering Technology program has been used as an opportunity to update or develop new laboratory projects that use learning in context, where student learning is applications based, delivered just in time, and allows for more free inquiry. One major revision to a laboratory project for a second year thermodynamics course allows students to explore how data acquisition systems are used to evaluate the performance of heat exchangers. This new experiment was successful in showcasing applied technologies to students and increased their confidence in working with real world equipment. Not all students enjoyed the open-ended format, which is a reminder that not all students progress at the same rate and with the same aptitude. The ideal laboratory project will accommodate all types of student learners.

References

[1] A. Keating, *Teaching Transformation: Transcultural Classroom Dialogues*. New York, NY: Palgrave Macmillan, 2007, pg. 126.

[2] K. McGonigal, "Teaching for Transformation: From Learning Theory to Teaching Strategies", *Speaking of Teaching*, vol. 14, no. 2, spring 2005. [Online]. Available: The Center for Teaching and Learning, Stanford University: https://web.stanford.edu/dept/CTL/cgi-bin/docs/newsletter/transformation.pdf. [Accessed Jan. 31, 2018].

[3] T. Finley, "4 Things Transformational Teachers Do", *Edutopia*. July 28, 2014. [Online]. Available: George Lucas Educational Foundation: https://www.edutopia.org/blog/big-things-transformational-teachers-do-todd-finley. [Accessed Jan. 31, 2018].

[4] P. Cranton, *Understanding and Promoting Transformative Learning: A Guide to Theory and Practice*. Sterling, VA: Stylus Publishing, 3rd ed. 2016, pg. 46.

[5] I.P. McPhail, "Transformation of a College: From Teaching to Learning," *Presidency*, vol. 7, no. 3, pp. 28-31, Fall 2004. [Online]. Available: ERIC Institute of Education Sciences: https://eric.ed.gov/?id=EJ796173. [Accessed Jan. 31, 2018].

[6] I. Busch-Vishniac, et al., "Deconstructing Engineering Education Programmes: The DEEP Project to reform the mechanical engineering curriculum," *European Journal of Engineering Education*, vol. 36, 2011 – issue 3, pg. 275. [Online]. Available: Taylor & Francis Online: http://www.tandfonline.com/doi/abs/10.1080/03043797.2011.579590. [Accessed Jan. 31, 2018].

[7] S. Dorado, "Institutional Entrepreneurship, Partaking, and Convening," *Organization Studies*, vol. 26, issue 3, 2005, pp. 385-414. . [Online]. Available: Sage journals: http://dx.doi.org/10.1177/0170840605050873. [Accessed Jan. 31, 2018].

[8] Biodiesel Supply store: "Stainless Steel Copper Brazed Plate Heat Exchangers." [Online]. Available: DudaDiesel.com: http://www.dudadiesel.com/heat_exchangers.php. [Accessed Jan. 31, 2018].