The remaining experiential learning activities in this project included a jigsaw activity with worksheets to recall how to calculate individual and overall heat transfer coefficients, an experiment to determine the specific heat capacity of milk, and a gallery walk to show different types of heat exchangers.

During the module, brief lectures (10 minutes) provided an introduction to pasteurization, and two methods to design heat exchangers (log mean temperature difference and effectiveness-NTU). The lectures were followed by time for the students to work on example problems and the project.

Results from experimental portion

In the laboratory course the students are taking concurrently, they calculate the individual and overall heat transfer coefficients for a shell and tube heat exchanger. For the project, instead of repeating a similar experiment, they warmed milk with an electrical heater they constructed, measured the temperature increase over time, calculated the energy input, and estimated the specific heat capacity of the milk.[18] This experiment was chosen to give the students an opportunity to observe how electrical energy can be converted into heat, and to calculate the heat supplied from the voltage and current readings. It was simple, took less than an hour, and cost very little. Details of the experiment are provided online.[18]

Students prepared temperature as a function of time plots and analyzed the data in several ways. Most students chose a short time period near the temperature in which they were interested, and estimated Cp at that temperature. A few students fit a polynomial to the data, and used the derivative to find an equation for specific heat of milk as a function of temperature. The error between the measured values and literature values was 20 – 30%, but students recognized that better insulation during data collection would improve the results. In their reports, several students suggested specific ways to reduce heat loss. All of the students were able to complete the calculations.

Student learning

As in Project 1, the students experienced multiple types of delivery modes. Making cheese in the classroom, then seeing it made at the farm reinforced the process and the purpose of each ingredient. Some students contacted the farmers as they worked on their project to verify the cheese making conditions.

This time they were more familiar with the jigsaw activity and gallery walk. The jigsaw activity helped them efficiently recall the different correlations for film coefficients (h) they had learned the previous semester, and they were able to apply them to example and homework problems. They also learned that the correlations used to calculate the film coefficient for flat plate heat exchangers are usually proprietary, but their textbook provided an acceptable one.[12] During the gallery walk, each group prepared a poster describing a different type of heat exchanger, using information from the textbook and brochures from different manufacturers. The students learned about several different types and quickly learned that flat plate heat exchangers are common in the food industry.

After a brief lecture on pasteurization, the students were given a worksheet to design a system given the specific dimensions of the unit. Diagramming the pasteurization process with the regeneration loop in the middle was difficult—many could not visualize how one stream of milk could heat and cool itself. In the future, bringing a long length of tubing to class would simplify the explanation.

The second brief lecture presented the two common methods for designing a heat exchanger, and the situations where each would be best suited. To reinforce the use and necessity of the log mean temperature difference, the students were given an example of a counter-current heat exchanger, and using a think-pair-share exercise, asked to determine temperature driving force. At the end of the discussion, they completed a worksheet using each design method. They referred to these worksheets while working on the project. These mini-lectures and worksheets provided the scaffolding for the PBL.

The design project was open-ended, but this time the students were more comfortable with the process. The groups used both methods of heat exchanger design. One group contacted a heat exchanger manufacturer and used the dimensions of a commercially available flat plate heat exchanger as the basis for their calculations. Another group developed a versatile spreadsheet for the farmer to use to determine how many plates he would need depending on the current amount of milk (the farmers had mentioned the seasonal variation in milk quality and supply). The students recognized one main advantage of the flat plate heat exchanger—it is easy to adapt the size by changing the number of plates.

Assessment of learning

The student learning objectives for this module were assessed primarily in the project reports the students prepared, but other qualitative methods were used as well and are summarized in Table 3.

ChE errata

Due to a production error, there is one symbol missing in the paper "Level Control..." by Larry K. Jang, published in the Fall 2016 issue of *CEE*. The letter "f" is missing in the final print. Eq. (1) on Page 245 should appear like

$$q = f(x,h) = C_v(x)\sqrt{\frac{\Delta P_{valve}}{S.G.}} = kx\sqrt{h} \qquad (1)$$