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Psychrometric charts in color: An example of active learning for chemical engineering students and faculty members

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ABSTRACT

This paper reports the design and scale-up of an active learning exercise centered around color coding of psychrometric charts. The initial version of this exercise was used with small classes of 60 students. When the class size doubled to 120 students, the previously successful exercise failed. The failure was then used as a workshop example for faculty development. The participants successfully identified a number of details of planning and implementation which could be improved, and the revised exercise was once again successful in the classroom. The results are a framework for design of active learning exercises, a number of lessons learned about how to successfully implement active learning in large classes, and a highly polished 2-lecture unit on psychrometric charts, including two animated and worked examples which form part of the paper.

1. Introduction

Psychrometric charts are one of several graphical solutions for material and energy balances. They combine a complex data set with a range of applications, many of which can be drawn from the students' real life experiences. Teaching these successfully allows students to deepen their understanding of combined material and energy balances, but teaching them murkily leaves the students confused and can erode their confidence at a crucial transition point in the material and energy balances course.

Of the recent publications on teaching psychrometric charts, (Erdelyi and Rajko, 2016; Mago and Long, 2016; Maixner and Baughn, 2007) all authors agree that the charts are overwhelming to students when they are first encountered. One author proposes an extensive module where two to three lectures are spent learning the intricacies of the charts as the students reconstruct the chart using an excel spreadsheet template. The class then uses the spreadsheet to construct charts at different ambient pressures and completes a laboratory exercise with a sling psychrometer (Maixner and Baughn, 2007). Another author proposes color coding the charts, but in a simplified excel spreadsheet without energy balances (Erdelyi and Rajko, 2016). The element of setting pencil to paper, which we use here, is a faster way for students to develop an understanding of how the charts are constructed and the data is structured. It also engages tactile and kinesthetic modes of internalizing understanding.

In this learning module, students color-code copies of the psychrometric charts (also referred to here as the "psychedelic" charts) in an active learning exercise. The collaborative team exercise addresses kinesthetic, visual, and active learning styles, and provides an ideal environment from which to build classroom discussion while building shared vocabulary. By the end of the first class, the co-incidence of 6 layers of lines, 8 kinds of data, and three thermodynamic paths is becoming clear to the students. The examples which follow in the next lecture literally animate the charts and provide students with experience in applying the charts to several classical problem types.

Recent papers on active learning are deepening our understanding of the elements of successful learning design. In one meta-study, the authors conclude that STEM students' learning increases by 50% or more when active learning is used

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(Freeman et al., 2014). In a second study (Andrews et al., 2011), authors broadened their investigation from instructors who are educational researchers well versed in learning design to academics who were using active learning tools (e.g. iclickers) without any knowledge of the fundamentals. Use of active learning tools alone had no effect on student learning. The key elements which must be present for active learning to work are:

1) an awareness of common misconceptions, and exercises which are designed to have students uncover or confront those misconceptions,
2) students need to be given or shown a conceptual framework which helps them to understand the relationships between ideas and their application, and
3) the design of the active learning exercise is extremely important for learning.

The next two sections identify common misconceptions which slow down students as they learn about the psychrometric charts, and common misconceptions which stall the implementation of active learning by professors. In both cases, the related learning objectives are also identified.

1.1. *Psychrometric charts for undergraduate learners*

Misconceptions

- reading data charts is a trivial undertaking
- charts contain one, or at most two, sets of data
- a single layer of lines or an axis can only hold one set of data
- paths and data are somehow the same
- the basis is always referred to a quantity of a process stream (vs. a kg of one component, but in this case, the basis is per kg of dry air)

Learning objectives

- given two pieces of data, accurately locate a process stream on the psychrometric charts
- accurately identify all of the available data for any point on the psychrometric charts, using the common language of color coding to help with your identification
- given a process description, decode the problem statement and provide an accurate representation of the thermodynamic path on a psychrometric chart, again, using the common solution language and color coding we have discussed
- use data at several process points along a process path on the chart to solve a material and energy balance related to moist air
- given a problem statement, evaluate whether the problem involves only moist air and whether the psychrometric charts are a useful tool to solve the associated material and energy balances
- be able to explain the use of the psychrometric chart to another student, an industrial supervisor, or a plant operator

1.2. *Developing faculty members' pedagogical skills in active learning*

Misconceptions

- active learning is a mysterious skill which can only be successfully implemented by extroverts who are at ease in conversation
- it is not reasonable to have classroom discussions about engineering principles because they are unambiguous facts
- active learning is a waste of precious class time

Learning objectives

- identify details which can be critical to the success of an active learning module
- explicitly design staged trust building in an active learning exercise to build student engagement
- design active learning elements to engage many parts of the learner's brain in the same task: in this example both visual and kinesthetic, with color as an added dimension of information
- use animations to illustrate complex graphical solutions more clearly
- experience through example how successful active learning design can directly address misconceptions by forcing the students to struggle with conflicting ideas as they shift to a new conceptual framework
- identify the elements of several examples which are designed to first solidify new concepts, then illustrate various aspects of solutions by applying the new (tool, framework, or idea) to progressively difficult problems

2. Implementation in the classroom: the devil is in the details

The psychrometric charts contain 6 layers of lines, with 8 sets of data and three different thermodynamic paths. Each of the three thermodynamic paths coincides with a data set, and three of the data sets are related to temperatures. While the paths make sense to expert learners, the density of information in the charts makes them at once powerful and difficult to decipher. This learning activity is designed to have students engage closely with the charts while they color-code the data. The module was first implemented in classes of 60 students. When the classes doubled in size, the module failed. In a faculty development workshop, the problem was deconstructed and redesigned. The next time the activity was run in the classroom the suggestions made by faculty members were implemented and all of the difficulties were resolved. In a third layer of development, the example problems were animated, again, to allow clearer presentation in very large classes. The resulting material is posted on-line with this article (see Appendix A in Supplementary data). Q5

2.1. *First implementation: 60 students and an overhead projector*

The psychedelic charts were first introduced in a mass and energy balances course at the University of Alberta in 1995, when class sizes were fairly small. Students were asked to bring their textbooks to class on a designated Friday. Presharpened colored pencils were distributed in mugs, with the students asked to select a set of 6 different colors of pencils. The first class was spent coloring the charts in their textbooks according to the following legend, which was written on the board:

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