Creating and Utilizing a "Working Model Heat Pump" to Enhance Student Learning in a Construction Management Program

David. W. Carns, MSCE, PE and P. Warren Plugge, Ph.D.
Central Washington University
Ellensburg, Washington

This paper explains how a "working model heat pump" was designed, built in-house and incorporated into a mechanical systems course within a construction management program to enhance student understanding of the basic refrigeration cycle. An explanation of how a need for the physical model was identified is included, with reference to student learning styles. Designing the model, securing funding for the model and construction and integration of the model into the classroom is also presented. In addition, documentation of the benefit of utilizing the working model heat pump as a demonstration tool to enhance student learning in two separate courses is included and discussed. Future research and opportunities to utilize this model in other courses have also been identified.

Key Words: Heat Pump, Mechanical Systems, Student Learning, Construction Management, MCAA

Introduction

A three-credit (quarter system) course in building mechanical systems is included as a requirement in the Construction Management program at Central Washington University. The course, which may be taken by students either at the junior or senior level, covers the basics of psychrometrics, building heat loss and gain calculations, heating and cooling equipment and building supply and drain-waste-vent plumbing systems. While the course is primarily lecture-based it also includes several field trips to observe mechanical systems on the university campus. As part of the coverage of air conditioning, chillers and heat pumps students are introduced to the refrigeration cycle. While not complex, concepts of the refrigeration cycle are difficult for some students to understand. Texts on mechanical systems show schematics of the cycle, accompanied by photographs of commercially manufactured refrigeration units, chillers, etc. Faculty members teaching the course noticed a conceptual disconnect in student learning between understanding the schematic drawings and visualizing the working components of the actual equipment. As a result of this observation student learning styles were researched, followed by design, funding and construction of a "working model heat pump", complete with pressure and temperature instrumentation. This model, which is currently utilized in the classroom, has provided students with a means to better visualize and understand working components of the refrigeration cycle. A relationship between utilizing the working model and student understanding was then measured and documented through the use of a questionnaire.

Student Learning Styles and Active Learning

Previous research at other institutions offering degrees in construction management indicates that construction students tend to be visual and hands-on learners. In 1999 a Midwestern university surveyed 73 undergraduate construction management students, mostly juniors and seniors, to better understand their personality types and learning style. Students were categorized by 16 different Myers-Briggs personality types. They were further separated into four simplified temperament groups. As a result of this research, it was found that 75% of the students have a sensing/judging temperament and these students like to reach conclusions following a step-by-step approach and put what they have learned to use. It was also discovered that 67% of the students preferred hands-on learning (Stein and Gotts, 2001). Research performed at Purdue University and the University of Nebraska pertaining to problems encountered when teaching mechanical systems in a construction management program led the authors to write: "We have found, through research, trial and error, experience, and good fortune, students invariably achieve a more comprehensive knowledge of mechanical systems if the text and lecture material is supplemented with visual examples and demonstrations" (Wentz & Alter, 1997, p 122).

In 2003, research was performed at California Polytechnic State University in San Luis Obispo, California to investigate approaches to active student learning with the idea of better engaging construction management students in the classroom. Researchers theorized that most construction management students are kinesthetic learners who prefer to learn by doing, as opposed to simply listening to a lecture. Team-building exercises were incorporated into two classes of fourth-year students to engage these students in active learning exercises. The authors of this study concluded that construction management instruction is most effective when it includes simulation of real-world scenarios. This includes active learning exercises which are meant to engage the students during class time (Gier and Hurd, 2004). Other research used physical pipe models to teach construction management concepts and bring hands-on learning to the classroom. These models were used to assist with pre-construction planning, construction scheduling and plan reading. Authors in this particular study concluded that "The value of physical models, as a teaching tool, is well documented and used extensively in a wide variety of fields" (Andersen & Andersen, 1993, p 2). At the University of Maryland Eastern Shore a variety of student-centered activities were incorporated into the construction management curriculum to enhance comprehension of engineering mechanics concepts. These activities led to an increase in the percentage of students passing the structures courses (Arumala, 2002).

The Idea of a Working Model Heat Pump

After teaching junior and senior construction management students in the building mechanical systems course for a number of years it was found that these students had difficulty understanding the refrigeration cycle. Schematics were incorporated in the textbook and in classroom lectures, complete with an explanation of the purpose of the components, system pressures, temperatures, refrigerant flow and phase changes etc. In addition, a residential-sized heat pump was purchased and turned into a display that could be utilized in the class. This heat pump was mounted on wheels, the top and front panels were made to open on hinges and the major components (compressor, expansion valve, four-way valve, condensing coils, etc.) were identified with labels. Students were given the opportunity to study the labeled heat pump and sketch the major components as part of a lab exercise within the course. While this proved helpful it was found that there was still a major disconnect, from the students perspective, between the two dimensional schematic drawing and the labeled three-dimensional heat pump. Students had difficulty comprehending the flow of the refrigerant in the system, the high and low pressure and temperature and the significance of refrigerant phase changes. While students could memorize and draw a refrigeration cycle schematic they had difficulty identifying the physical components in real systems and offering a meaningful explanation of how these systems actually function, as identified by student performance on homework and exams. This became even more evident when the concepts of the refrigeration cycle were applied to more complex mechanical systems, such as water cooled chillers.

To bridge the gap in student learning between a basic understanding of a refrigeration schematic and full size heat pumps and chillers the idea originated to purchase or create a working model heat pump that could be utilized as a demonstration tool within the classroom. The theory was, given the learning styles of most construction management students, a highly visual, functioning model would help them better understand the system. A questionnaire was designed and utilized in two separate courses over a two-year period to measure and quantify the amount of student learning.

Design, Funding and Construction of the Working Model

Once the need to bring a hands-on refrigeration model into the classroom was identified the purchase of commercially manufactured educational training equipment was considered. Several models were considered, however the cost of these models was a minimum of $20,000 and far exceeded the amount of funds available to the program for this purpose. The faculty members in the construction management program became aware of a laboratory grant program through the Mechanical Contractors Association of America (MCAA). The purpose of the grant program was to make funds available to university programs with MCAA student chapters to cover all or a portion of the cost of equipment to be used to teach courses in mechanical construction or mechanical construction management. With this knowledge, faculty in the program consulted with the classroom support technician for the department and discussed the feasibility of building a working model heat pump in-house at a cost considerably less than what it would cost to purchase a commercially available model. With knowledge that the expertise was available locally to construct such a model, a preliminary design and budget was created and a grant was written and submitted to the MCAA for a "Working Model Heat Pump" on March 7, 2004 in the amount of $4925. The grant was approved in June 2004 and funds were received in September 2004.

With funding secured, schematics were discussed and developed and the major components of the system were selected. Since the goal of the model was to enhance student learning in a classroom environment the model was designed to be housed on a portable wheeled cabinet that could be easily moved into the classroom. In addition, the model was simplified by using hand operated valves. A relatively small compressor and large, easy-to-read pressure gages and digital temperature gages were selected. The following table includes the major components and the associated cost.

Table 1

Major components and associated cost

Component	**Approximate Cost**
½ Horsepower compressor (R134a refrigerant)	$460
Evaporator/condenser coils w/fan (two)	$440
Expansion valves (two)	$95
Reversing solenoid valve	$105
Digital pressure gages (two)	$440
Temperature gages and thermocouples (two)	$385
Sight glasses, additional gages, etc.	$580
Copper lines, fittings, etc.	$585
Steel frame, casters, wood panels, paint, etc.	$775
Refrigerant recovery system (used)	$480
Miscellaneous	$500
Total	$4845

The mechanical components were ordered, the steel frame, casters, wood panels and paint were purchased locally and construction begin. This was not an easy process, as there were a number of compatibility issues with the type of tubing, valves, soldered connections etc. Since this was not a high priority project the support technician worked on this model between other projects. It became operational and was utilized in the classroom for the first time in the spring of 2006. Figure 1 shows the completed unit.

Figure 1: The completed working model heat pump

Utilizing the Working Model Heat Pump in the Classroom

After becoming operational the model has been used as a demonstration tool in the sophomore level introductory blueprint reading course during the coverage of basic building mechanical systems and also in the junior/senior level mechanical systems course, where coverage of the refrigeration cycle is much more extensive. Because the system is portable and can be plugged into a standard 110 volt outlet it can be easily moved into a standard classroom. In addition, the model has large temperature and pressure gages that are easily visible and hence the students are able to immediately see the difference between the high pressure/high temperature side and the low pressure/low temperature side of the refrigeration cycle as soon at the compressor begins running. Because the condenser and evaporator coils are each equipped with a variable speed fan that blows air across a thermocouple sensor, the volume of air flow across the coils can be varied. During operation the corresponding air temperature immediately changes and is reflected as a change in reading on the gages. The students can see that, with the refrigerant flow in a steady state, increasing the flow of air across the evaporator coil, for example, results in a rise, rather than a drop, in the air temperature. The idea is to convey to the students that total heat change across the evaporator remains constant and increasing the volume of air flow must result in a smaller temperature difference. This is the type of concept that the students initially find confusing and counterintuitive.

Because the components of the system; the compressor, coils, fans, expansion valves, etc. are isolated and mounted on a clean, painted flat vertical panel they are very easy for the students to identify. Additionally, the copper tubing is also cleanly mounted on the vertical panel and this makes it easy for the students to follow the flow of the refrigerant through the system; from compressor, to condenser to expansion valve to evaporator and back to the compressor. A four-way solenoid valve is also included in the model, making the system reversible so that it can be operated as a heat pump. Reversing the system in the classroom allows the students to visualize change in flow of the refrigerant and the reversal in temperatures and pressures as the condenser and evaporator coils change roles. In order to simplify the system, manual valves were included to reroute the flow of the refrigerant, in addition to the four-way valve. Hence reversing the system can be accomplished in only a few minutes.

As soon as the model was demonstrated in the classroom student feedback was immediately positive, although mostly anecdotal. Verbally, students in the mechanical systems class mentioned that they felt they better understood the various components of the system and their function. They also felt that they would now be able to identify the physical components of the refrigeration cycle and apply their knowledge to more complex real-life systems. As part of university policy, all students are given the opportunity to evaluate the instructor and the course at the end of the quarter through a standard teaching effectiveness evaluation questionnaire. They are also encouraged to provide written comments pertaining to the course. After delivery of the course using the model in the classroom there were several positive written student comments pertaining to its effectiveness. However, it was decided that it might prove beneficial to document and quantify student learning that took place as a result of using the model in the classroom.

Questionnaire for the Working Model Heat Pump Demonstration

To determine if the construction management students were really getting something out of the demonstration, a questionnaire pertaining to the knowledge, and perceived knowledge, gained through the demonstration was developed. This three page questionnaire is very simple. The first page consists of four questions and the next two pages consist of a series of photographs of four components of the refrigeration cycle (evaporator, four-way valve, compressor and expansion valve). Three questions are self-evaluation questions pertaining to perceived knowledge gained by the demonstration and the other question pertaining to a schematic is included to measure students' knowledge. This questionnaire was distributed to a group of 31 students in the spring of 2007 in a building systems course and to 24 students in same course in the winter 2009. In each case the questionnaire was given to the students immediately following a classroom demonstration using the model. The first page of the questionnaire is included below for reference. The actual questionnaire given to the students provided more space for answers.

Questionnaire for Working Model Heat Pump Demonstration

This questionnaire is being distributed to gain information to determine how the "working model heat pump" demonstration contributed to your understanding of the refrigeration cycle.

1. To what degree do you feel that your knowledge and understanding of the refrigeration cycle was enhanced by the "working model heat pump" demonstration?
Please circle the most appropriate response.

Not enhanced 1 2 3 4 5 6 7 8 9 10 strongly enhanced

2. Which aspect of the display was the most beneficial? Please provide a short explanation.

3. Based on what you learned from the demonstration, ***draw a schematic*** *of the refrigeration cycle, labeling all four major components.*
4. Based on what you learned from the demonstration, do you feel that you can ***explain*** *the refrigeration cycle to someone who has no prior knowledge of the cycle? Please circle the most appropriate response.*

a. Yes, with confidence
b. Yes, with minor difficulty
c. Yes, with major difficulty
d. Not sure
e. No

Results

After the questionnaire was administered the results were analyzed and evaluated to determine the students' level of perceived knowledge and their measured level of knowledge of the heat pump components. Descriptive statistics were run on the results of the self evaluation questions for a sample of 55 participants, shown in Table 2. The questionnaire was created to allow students to respond numerically. For the questions on their perception of knowledge gained the range was from 1, indicating their knowledge was not enhanced, to 10, indicating that their knowledge was strongly enhanced. For the questions on their confidence in their knowledge gained the range was from 1, indicating that they did not feel comfortable with their knowledge, to 5, indicating that they felt confident that they could explain the refrigeration cycle to others.

Table 2

Descriptive statistics of self evaluation

	Minimum	Maximum	Mean	SD
To what degree was your knowledge enhanced?	3	10	7.36	1.53
What is your confidence in your knowledge of heat pumps?	2	5	3.82	0.82
(N=55)				

From the responses to the self evaluation questions students definitely felt their level of knowledge was enhanced through the use of the model in the demonstration, with a relatively high mean (M = 7.36, SD = 1.53). Also, students perceived their level of knowledge to be relatively high after participating in the demonstration (M = 3.82, SD = 0.82). In addition to the self evaluation questions, students were tested on their knowledge of the heat pump components after the demonstration. Table 3 shows the descriptive statistics for the students' knowledge of heat pumps when instructed to draw a schematic detail and identify four pictures of components in the heat pump process.

Table 3

Descriptive statistics for students' knowledge of heat pumps

	Minimum	Maximum	Mean	SD
Schematic	2	3	2.76	0.43
Component Identification	0	4	3.16	1.00
(N=55)				

For the schematic, students' level of knowledge was scored based on the drawn detail, with a grade ranging from 0 to 3. With the use of the heat pump model in the demonstration, Table 3 shows students were able to draw a schematic of the heat pump with a relatively high level of accuracy (M = 2.76, SD = 0.43). Component identification scores had a possible range of 0 to 4, based on the number of photographs of components properly identified. After using the demonstration model, students were able to identify heat pump components with a high level of accuracy (M = 3.16, SD = 1.00).

A simple Pearson correlation was calculated to show the association between the students' perceived knowledge gained, as measured by the self-evaluation questions in the questionnaire and their actual knowledge, as measured by component identification r_s (53) = .08, p = .55. Figure 2 shows these results in graphical format.

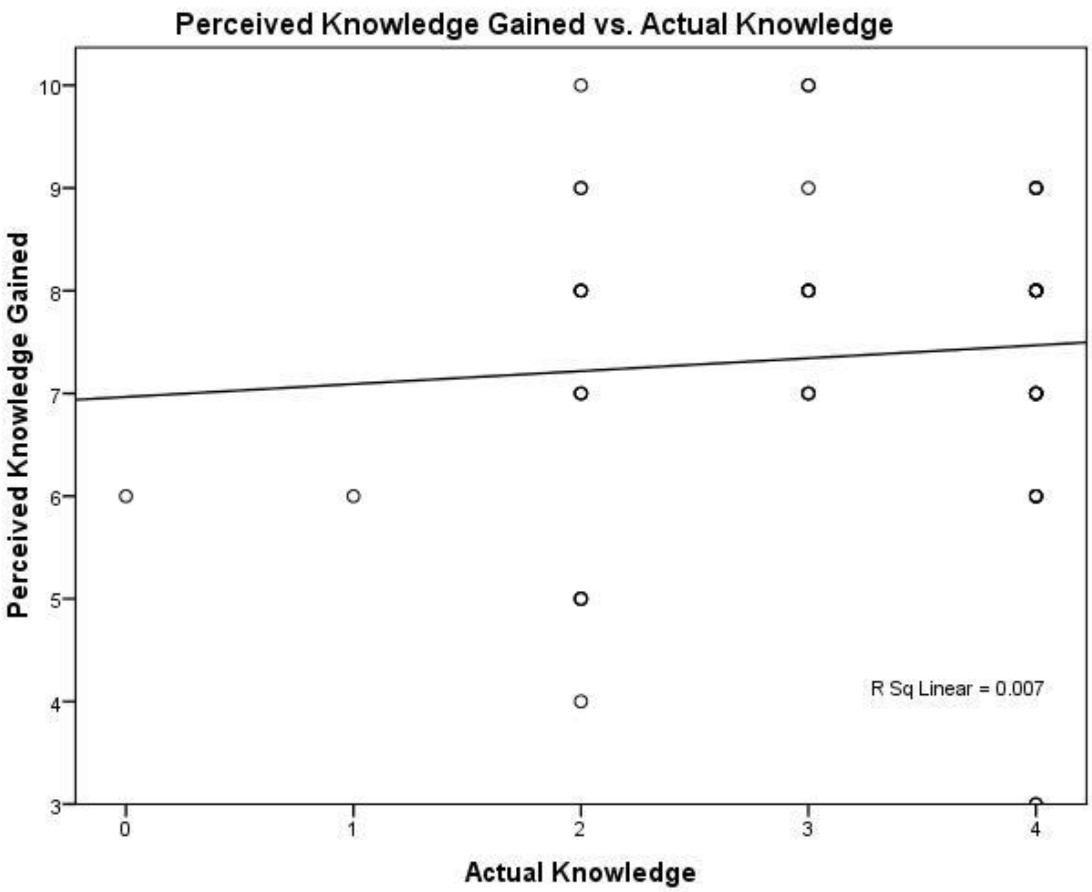

Figure 2: Correlation plot of perceived knowledge gained and actual knowledge

Although the statistics show very little correlation between the two variables measured, Figure 2 does indicate a small level of association between perceived knowledge gained and actual knowledge.

Conclusion and Further Research

The purpose of this research was to expand the body of knowledge on learning styles and demonstrate that construction management students are active learners who gain comprehension of more complex concepts, such as mechanical systems, as visual and hands-on learners. This research also provided an economical approach to design, build, and secure funding for a heat pump model to be used as a demonstration component to address the visual learning style of many construction management students.

Areas of further research include dividing a class of construction management students into two groups. The first group would act as the control group and would be exposed to an explanation of the refrigeration cycle through traditional methods, such as photos and schematic drawings. The second group of students would be taught the same material using both a verbal explanation and the working model heat pump. A similar questionnaire would then be used to measure the knowledge gained by the two groups of students, followed by a comparison of the two groups. Another area of future research includes the incorporation of additional physical models of mechanical system components into other construction management courses to enhance students' comprehension. It would also be interesting to determine, through the use of models in the classroom, the quantity and quality of information students retain over a period of time with the use of models as a teaching tools.

These findings can be used as a guide for other programs that seek to incorporate the use of complex models in construction management curriculum. Furthermore, because many universities have limited budgets, this research provides an alternative and an approach to secure the funding for teaching models that might otherwise be too expensive if purchased from a typical educational manufacturer. What can be concluded from this research is that there are economical approaches to design, build, and secure funding for mechanical models that will allow students to achieve a more comprehensive knowledge of mechanical systems, specifically the refrigeration cycle.

References

1. Kenneth W. Anderson and Norma Jean Anderson (1993). Using Physical Pipe Models to Teach Construction Management Concepts. *ASC Proceedings of the 29th Annual Conference, Colorado State University, Fort Collins, CO*, 1-6.

2. Joseph O. Arumala (2002). Student-Centered Activities To Enhance The Study Of Structures. *ASC Proceedings of the 38th Annual Conference. Virginia Polytechnic Institute and State University, Blacksburg, VA*, 1-16.

3. Dennis M. Gier and Marjorie W. Hurd (2004). Increasing the Effectiveness of Active Learning Exercises in the Construction Management Classroom. *ASC Proceedings of the 40th Annual Conference, Brigham Young University, Provo, UT.*

4. James Stein and Victoria Gotts (2001). Analysis of Selected Learning Preferences of Construction Management Students. *ASC Proceedings of the 37th Annual Conference, University of Denver, Denver, CO*, 41-48.

5. Tim Wentz and Kirk Alter (1997). Developing a Laboratory for Heating, Ventilating and Air Conditioning Courses. *ASC Proceedings of the 33rd Annual Conference, University of Washington, Seattle, WA*, 119-126.