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Teaching Methods

Integrating Hoop House Construction and Operation into an Undergraduate General Education Horticulture Class

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ADDITIONAL INDEX WORDS. Experiential learning, environmental data, season extender, teaching undergraduates

SUMMARY. We integrated the construction and operation of hoop houses into a general education course to provide students with basic agriculture skills such as basic agricultural construction, greenhouse crop production, and greenhouse environmental data collection, while immersing them in an experiential learning environment. Students in the class constructed three 12 × 15-ft hoop houses, installed an irrigation system and climate data acquisition system, and grew radish (*Raphanus sativus* 'Cherry Belle') and lettuce (*Lactuca sativa* 'Black-Seeded Simpson') within each hoop house. At the end of the exercise, 86% of students agreed that they knew the basic techniques of hoop house construction, and 89% agreed that they understood the practical application of building a hoop house. More instruction on calculating crop fertilizer requirements would benefit students because only 43% of students agreed or strongly agreed that they understood how to compute crop fertilizer requirements. Climate data demonstrated that air temperature within the unvented hoop houses exceeded the optimal growing temperature for lettuce and radish. We conclude that construction and operation of hoop houses provided practical agricultural skills in an experiential learning environment while revealing subject areas that warrant further instruction.

Introduction to Horticulture (HORT 100G) at New Mexico State University (NMSU) is a four credit hour, general education course that provides an introduction to the physical, biological, and chemical principles underlying plant growth and development in managed ecosystems (NMSU, 2007). Students complete laboratory exercises that complement principles covered in lectures. Enrollment in HORT 100G averages 50 students, and horticulture majors typically represent 25% of the class. The class meets for three 50 min lectures and one 2-h laboratory each week. Each of three laboratory sections has 15 to 17 students, with a teaching assistant (TA) assigned to each laboratory section.

At NMSU, instruction in HORT 100G routinely requires laboratory activities in a greenhouse setting, but detailed instruction on greenhouse operation and management is reserved for an upper division course, Greenhouse Management (HORT 488). Regardless of the class level, it is often impractical to construct a greenhouse as a class activity. With the average cost of a greenhouse ranging from $10/ft^2$ to $15/ft^2$, teaching institutions might find it financially prohibitive to build a greenhouse as a class exercise. The resulting lack of hands-on knowledge of how to construct a greenhouse is a potential gap in many horticulture curricula.

In contrast, field hoop houses average less than $1.5/ft^2$, thereby overcoming the financial limitation of building a greenhouse. Also, hoop houses are relatively easy to construct. Because they can be constructed easily and inexpensively, field hoop house construction might offer an excellent opportunity for immersing students in an active learning environment. Hoop house construction and operation can provide a unique opportunity for experiential learning in horticulture, basic agricultural construction technology, and greenhouse crop management. Environmental monitoring inside and outside a hoop house could help students better understand the impact of the environment on crop production. Furthermore, lectures in introductory horticulture courses such as HORT 100G can be matched to multiple hands-on activities that involve

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
2.54	inch(es)	cm	0.3937
16.3871	$inch^3$	cm^3	0.0610
0.4536	lb	kg	2.2046
48.8243	$lb/1000\ ft^2$	$kg{\cdot}ha^{-1}$	0.0205
1.1209	lb/acre	$kg{\cdot}ha^{-1}$	0.8922
0.0254	mil	mm	39.3701
28.3495	oz	g	0.0353
305.1517	oz/ft^2	$g{\cdot}m^{-2}$	0.0033
(°F − 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

hoop house construction and operation. Hoop house construction can be a powerful learning tool because in an introductory course students benefit immensely from hands-on laboratory exercises that relate to classroom materials (Bradley et al., 2003).

A hoop house is a structure that is used as a greenhouse or a season extender. These structures have a characteristic semicircular hoop shape with a frame typically constructed of lengths of PVC pipe (Upson, 2005). In New Mexico, a hoop house is usually covered with 6-mil-thick ultraviolet-resistant clear plastic (Jimenez et al., 2005). The expected life span of a hoop house cover is three growing seasons. In the United States, small producers often construct hoop houses to produce and sell fresh horticulture crops to local outlets beyond the normal growing season. To meet the technical needs of those producers, the Cooperative Extension Service conducts workshops and publishes pamphlets on how to build inexpensive hoop houses (Jimenez et al., 2005). However, hoop house construction is not an integral part of the curricula in U.S. horticulture programs.

A decision case study was used to help students select the site for high tunnels and other protected-environment structures (Spaw and Williams, 2004). However, we are unaware of any project that used the actual construction of a hoop house as an undergraduate learning tool. The objective of this article is to describe how the construction and operation a hoop house as a laboratory activity provided experiential learning opportunities for students in an introductory horticulture class. Our approach was to use the active learning environment that hoop house construction and operation created to provide students with basic agriculture skills such as greenhouse construction technology, crop production, calculating fertilizer application rates, and greenhouse irrigation and instrumentation.

Laboratory for the Introduction to Horticulture (HORT 100G) class

Introduction

The winter vegetable crop growing season in southern New Mexico can be extended using greenhouses. An inexpensive greenhouse can be constructed using hoop greenhouse construction. Previous construction methods are described in Circular 606, hoop house construction for New Mexico (http://cahe.nmsu.edu/pubs/_circulars/CR-606.pdf)[z]. Greenhouse hoop houses are ecosystems where the interior environment can be manipulated to suit a crop's need. Hoop houses can extend the growing season, since you may plant early. The collection of heat units in the hoop house is higher which results in an earlier harvest.

The objective of the laboratory is to get practical experience in building a hoop greenhouse and get experience in monitoring environmental conditions with data loggers that record the temperature inside and outside the greenhouse.

Materials and methods

1. Construct three greenhouses, 12 ft[y] wide by 15 ft long with five hoops for each greenhouse.

2. Follow the instruction in Circular 606 for determining the four corners of the greenhouse using the Pythagorean Theorem.

3. Hoop material will be 1.25-inch polyvinyl chloride (PVC) schedule 40 bought from Home Depot. Purchase 15 sections of pipe for the three hoop houses.

4. Place a string around the four corners to outline the hoop house's foundation. Along both lengths of the hoop house and inside the string, drive 36-inch rebar stakes vertically every 4 ft apart, 30 inches deep, bend to a 30° angle, until you reach the 15-ft length. Note that the last rebar will be only 3 ft from the previous rebar.

5. Install the hoops over the rebar.

6. After the hoops are in place, install three braces running along the length of the inside of the hoop house. These are for stability and will be made from 0.75-inch PVC pipe. If the PVC pipe comes in 10-ft lengths, put two sections together to make a 15 ft brace. Cut 5 ft from the second pipe. Mark the pipe where the tubular braces will be attached. The mark will be 72 inches from the end of the pipe, and also down the center of the hoop. Use a running string to mark the pipe. Mark the 0.75 inch PVC pipe every 48 inches.

7. Purchase plastic for the hoop greenhouse cover from Greenhousefilm.com (http://www.wilsonirr.com/greenhousefilm.html)[x]. Purchase greenhouse film (6-mil, 4-year life) that is 36 ft wide and 48 ft long for the two houses. If you do not purchase ultraviolet-resistant plastic it will not last one season. Dig a shallow trench along each side of the greenhouse to hold the plastic down and on both ends except where the doors attach.

8. To successfully attach the plastic covering, make sure there's no wind; work in the afternoon, when the plastic can heat up and stretch. Lay out the greenhouse plastic in a clean work area beside the hoop house. The plastic will be cut to the size required (using a straight edge, cut the plastic to 26 ft which is 6 ft longer than the width of the hoop house (20 ft). Consequently, the plastic will be 36 ft long (15 ft of length and 10.5 ft on each end to cover the end) and 26 ft wide. After the plastic is cut, find the edge of the cut piece and center it over the hoops by dragging gently across the top. Let the plastic rest on the hoops for 15 min to absorb heat. Keeping the plastic stretched, staple one side of the plastic to a 2 x 4 x 16-ft board, rolling the plastic and board together and placing both in a trench dug in the soil. Back fill the trench and then do the same on the other side.

9. On both ends of the hoop house, use 2 x 4 x 8-ft board to construct a frame for a door. Size door 4 ft wide and height of the hoop house. Staple plastic to frame and install lathe pieces to hold plastic, or design a door and cover with plastic and hang the door on the frame. Cut out the door plastic and roll up to enter or open door. The rest of the end plastic is stapled to 2 x 4s, rolled and put in the trench.

Monitoring of air and soil temperature

1. Measure air and soil temperature with HOBO[z] sensors in and outside the greenhouse. Download data using a portable computer. Purchase a HOBO[®] H08 (Onset, Pocasset, MA) temperature data logger for $59 and place in a solar radiation shelter to measure air temperature. To measure soil temperature, put the data logger in a sealed plastic bag and bury 5 cm into the soil. See http://www.onsetcomp.com/products/data-loggers/h08-030-08[w].
In order to download the data, purchase the Boxcar software from Onset at http://www.onsetcomp.com/products/software/bhw-pc[v].
See the Onset webpage for instruction on how to download data.
The radiation shelter can be purchased from Onset at http://www.onsetcomp.com/products/mounting/m-rsa[u]. Or you can make one from 6-inch diameter plastic plates purchased at Kmart. For this Lab, both the shelter and the HOBO[®] data loggers will be supplied.

2. Generally the end plastic door will need to be opened by 10:00 in the morning and closed by 4:00 in the evening. Determine the maximum allowable temperature in the greenhouse by going to the internet and looking up the optimal temperature for winter crops. Determine from the air monitoring and the outside temperature exactly when the plastic door should be open in the spring after the plants have been planted. Run an experiment with different times of the house being open to determine the ventilation time needed to keep the house from over heating.

Planting

Select plants in the spring to be planted in the greenhouse. Look at the temperature difference between the inside and outside of the greenhouse to determine how soon you can plant. Do not plant until the soil temperature reaches 50 °F.

Install irrigation system

The irrigation system will be soaker hose. To determine the flow rate of the soaker hose, connect it to a faucet outlet and put in washtub. Run for 30 min and measure volume of water. When irrigating, run the irrigation system long enough to satisfy the ET (evapotranspiration) since the previous irrigation. Get ET_o (reference crop evapotranspiration) from the internet at http://weather.nmsu.edu/PET/JS_pet.htm[t]. Scale the ET_o of outside the greenhouse to the ET of the plants in the greenhouse. ET = ET_o x area of plants. Time of run = ET/application rate. Irrigate three times a week (Monday, Wednesday, and Friday). To start irrigation, run the irrigation system long enough to moisten the soil to 4 inches on each side of seed.

Report for fall course

1. List tools and materials needed.
2. List cost of material (get from Home Depot).
3. Keep track of time and calculate labor cost at $10/h.
4. Plot soil and air temperature inside and outside greenhouse and explain difference.
5. Determine the ventilation time needed to keep the greenhouse from over heating as related to air temperature.

[z]Jimenez et al., 2005.
[y]1 ft = 0.3048 m, 1 inch = 2.54 cm, 1 mil = 0.0254 mm, (°F - 32) ÷ 1.8 = °C.
[x]Greenhousefilm.com, 2005.
[w]Onset, 1996a.
[v]Onset, 1996b.
[u]Onset, 1996c.
[t]New Mexico State University Climate Center, 1996.

Fig. 1. Handout distributed to Introduction to Horticulture (HORT 100G) students at New Mexico State University before students started constructing a hoop house as a laboratory exercise.

Materials and methods

Preconstruction activities. Before hoop house construction began, students received an extension publication (Jimenez et al., 2005) on the construction of a hoop house and a handout that described the construction process (Fig. 1). A student worker acquired hoop house materials (Table 1) and constructed the hoop portion of the house. All three laboratory sections met simultaneously for the construction process, which took place during the assigned laboratory period. Students were divided into four workable groups of 10 to 11 students. Each group was assigned a task that was rotated among the groups so that each group participated in all construction activities. A TA was assigned to three of the four groups and the instructor explained how to calculate fertilizer application rates to the fourth group. Three hoop houses were built.

Table 1. Construction materials, seed, and fertilizer inputs needed for Introduction to Horticulture (HORT 100G) students to build and plant three 15-ft (4.6 m) hoop houses at New Mexico State University. The assembly of the materials and seeding the greenhouse required an assortment of tools.[z]

Description[y]	Quantity	Unit[y]	Unit price ($)	Total price ($)
1.25-inch polyvinyl pipe (PVC)	15	20 ft	8.80	132.00[x]
6-mil plastic	36 × 72 ft	1 roll	215.00	215.00[x]
Garden hose	3	1	11.99	35.97
Soaker hose	3	1	13.99	41.97
Drill bits	2	Packet	2.39	4.78
Wood screws	3	Box	4.11	12.33[x]
Staple gun	3	1	15.99	47.97
Staples	1	Box	2.99	2.99[x]
Wood (2 × 4 × 8 ft)	42	1	2.09	87.78[x]
Rebar (1/2 inch)	15	8 ft	4.27	64.05[x]
Lettuce seeds	12	1-g packet	1.49	17.88
Radish seeds	12	1-g packet	1.79	21.48
Granular fertilizer	1	30-lb bag	17.00	17.00
Total cost				701.20

[z]Portable power drills, hand saws, hammers, staple guns, and shovels were used.
[y]1 inch = 2.54 cm, 1 ft = 0.3048 m, 1 mil = 0.0254 mm, 1 g = 0.0353 oz, 1 lb = 0.4536 kg.
[x]Total structural materials cost = $514.15 or $171.4 ($0.95/ft^2) per hoop house; $1.00/ft^2 = $10.7639/m^2.

Student hoop house construction. The hoop house design was modified from the original presented in the extension circular because we judged the new design to be easier to construct. Main differences included the addition of a trench outside the hoop house to secure the plastic over the hoop house and construction of clear plastic doors to allow sunlight to enter the house from all sides. Hoop houses were constructed on flat, sandy soil, which allowed the students to dig the trench, install the plastic, and build at least one frame and one door in 2 h. A student employee finished the remaining door and frame (Fig. 2A).

After the door frame was constructed, students built the door by framing it with warp-free, 2 × 2-inch lumber. The ends of the wooden frame were butted together and fastened with steel and wooden angle supports, and the door was then covered with plastic.

After the door frames were installed and the outside trenches were dug, 6-mil plastic (in a roll) was installed by first unrolling it on the grass. This allowed the plastic to warm up enough to become pliable. The plastic was re-rolled along its length, placed along the trench, and unrolled over the hoop frame (Fig. 2B). One end of the plastic was then stapled length-wise to a 2 × 4-inch post. The plastic was rolled up several times around the post to secure the extra plastic, and the plastic and post were placed in the trench and backfilled with soil (Fig. 2C). Similarly, the other end of the plastic was attached to a 2 × 4-inch post after the plastic covered the hoop. The plastic was rolled up around the post, placed in the trench, and the trench was backfilled. This trench construction method anchored the hoop house to the ground and stabilized the structure (Fig. 2, D and E). Also, by using this method, the plastic could be tightened if needed by mounding more soil against it (Fig. 2C).

Calculating granular fertilizer application rates. To calculate granular fertilizer application rates, students worked with United States and metric units. To facilitate calculations, students were asked to assume that 4 lb/1000 ft^2 nitrogen (N) were needed during the growing season based on the recommended fertilizer needs of tall fescue grass (*Festuca arundinacea*). Because students worked on fertilizer calculations while in the field and did not always have quick access to calculators, assumptions were that the conversion of pounds per acre to kilograms per hectare was 1 lb/acre = 1 kg·ha^{-1} instead of 1 lb/acre = 1.1209 kg·ha^{-1}, and that there were 43,000 ft^2 rather than 43,560 ft^2 per acre.

After the recommended fescue grass fertilizer application rate of 4 lb/1000 ft^2 N was converted to pounds per acre (172 lb/acre), students first discussed how the fescue fertilizer rates compared with the 300 lb/acre N that farmers normally applied to corn fields. Next, they converted total N needed in 172 lb/acre to 172 kg·ha^{-1} and then converted it to grams per square meter (17.2 g·m^{-2}). After the students calculated the total amount of N, they were asked to give the number of required fertilizer applications. Although the answer varied from one to five, most students thought that four applications were reasonable. Consequently, the application in grams per square meter (17.2 g·m^{-2}) was divided by four (4.3 g·m^{-2}) and multiplied by the area of the greenhouse in square meters. Because the internal area of the hoop house was 180 ft^2 (15 × 12 ft), students had to convert square feet to square meters (16.72 m^2).

Students were provided with 16N–3.5P–6.6K (3% ammoniacal N + 13% urea) granular fertilizer. Total N requirement (71.9 g) was divided by 0.16, the amount of N per gram of fertilizer, to determine the weight (449.3 g) of fertilizer to apply. Because a volumetric flask was used to measure the amount of fertilizer, students discussed whether the fertilizer was denser or lighter than water. They assumed that the density of the granular fertilizer was 1 g·m^{-3} and measured this volume (449 cm^3) into a hand fertilizer spreader (Scotts Easy Hand-held, model 71030; Scotts, Marysville, OH).

One student volunteered to teach the others how to estimate the density of a granular fertilizer. One hundred cubic centimeters of fertilizer were placed into a 100-cm^3 volumetric flask, which weighed 137.7 g when full and 41.3 g when empty. Students were asked to recalculate the fertilizer application rate using the experimentally derived density (0.96 g·m^{-3}) and to determine the magnitude of the error that occurred when they assumed that the granular fertilizer density was 1 g·m^{-3}.

Fertilizer was applied first (by the students) to all three hoop houses on 11 Oct. 2006. The TAs applied fertilizer on 30 Oct. 2006 and 15 Nov. 2006. A fourth fertilizer application

Fig. 2. Students in the Introduction to Horticulture (HORT 100G) class at New Mexico State University excavating a trench that will secure the plastic of a hoop house (A) and installing the plastic cover over a hoop house that has the door and frame completed (B and C); the interior of a completed hoop house showing a planted crop and data acquisition systems (D); three student-built hoop houses (E).

was not given because the plants did not require it. Students received a handout on calculating fertilizer rates to strengthen their skills in fertilizer calculation methods. The course was repeated in 2007 using the three fertilizer application schedule.

SOIL PREPARATION AND SEEDING THE HOOP HOUSES. On 11 Oct. 2006 and 18 Sept. 2007, seeds of 'Cherry Belle' radish (*Raphanus sativus*) and 'Black-Seeded Simpson' lettuce (*Lactuca sativa*) were hand-sown in two sets of three 12-ft-long rows, spaced 10 inches apart. Rows were made on each side of the hoop house and were separated by a 3-ft aisle (Fig. 2D). Before sowing, soil was hand tilled but not mounded into ridges and furrows. After sowing, fertilizer was applied with the hand spreader, and the rows were irrigated with the soaker hose (Fig. 2D).

We selected radish and lettuce because radishes require only 30 d to mature, and lettuce can be cut, allowed to regrow, and harvested repeatedly. In the first year, we opted to allow the radish and lettuce crop to grow until 1 Jan. 2007. By Dec. 2006, the radish had formed seed heads. In 2007, crops planted in September were harvested at the end of the semester. Seed and fertilizer cost $56.36 for three hoop houses (Table 1).

INSTALLING CLIMATE MONITORING EQUIPMENT. After sowing, a data logger (HOBO® H08-004-02; Onset, Pocasset, MA) equipped with a TMC6hd soil temperature probe (Onset) was installed in beehive solar shelters inside each hoop house. The data logger was placed 5 ft from the door and adjacent to the row closest to the aisle (Fig. 2D). A similar data logger and temperature probe were installed outside and between the first and second hoop houses. Solar shelters were installed at 1.5 ft above the ground. Data loggers recorded ambient air temperature, relative humidity, and light intensity with internal sensors, and recorded soil temperature with a probe inserted 0.5 inch into soil adjacent to the plants.

Data loggers were enclosed in beehive solar shelters to protect them from the environment and to ensure that ambient air temperature was measured correctly. Several students downloaded environmental data from the data loggers weekly using a portable computer. Data were imported into Excel (Microsoft, Redmond, WA), graphed, and presented to the class. Students who worked on the environmental data received extra course credit.

Students installed and programmed an automatic, four-station irrigation controller (model 57004, WaterMaster; Orbit, Bountiful, UT) to control irrigation duration. During germination, seeds were irrigated three times a week for 10 min. After germination, seedlings were first irrigated two times a week for 10 min, then irrigation duration was increased to three times a week for 20 min when full crop cover occurred. Irrigation was sufficient to fully saturate the planting beds.

COURSE EVALUATION. The course repeated in Fall 2007 used a course evaluation tool to measure course outcomes. The evaluation tool consisted of five-point Likert-scaled items (Ary et al., 1996). The scaled value for each response category was as follows: strongly disagree = 1, disagree = 2, undecided = 3, agree = 4, and strongly agree = 5. Questions that were Likert-scaled were related to classroom and laboratory instructional delivery, knowledge of the construction and practical uses of hoop houses, fertilizer requirements for hoop house growth, and the importance of hoop house instrumentation.

Data analysis. Course evaluation data were analyzed using SAS (version 9.1.4 for Windows; SAS Institute, Cary, NC). PROC UNIVARIATE revealed that evaluation data were normally distributed. Least significant difference ($P \leq 0.05$) was used to identify statistical differences among least squares means of scaled items.

Results

Benefits of the course. Building a hoop house as a class activity provided a practical approach to teaching topics that exist in many standard horticulture curricula. Topics such as calculating fertilizer rates for greenhouse crops were only part of the HORT 100G lecture, but this course allowed us to support the lecture topic with a hands-on laboratory. A major benefit of this course was student exposure to basic agricultural construction technology in an introductory rather than an advanced level course. The building of a hoop house as a class exercise provided a simple and inexpensive way for instructors to teach the construction and climate instrumentation of protected-environment structures. For example, the construction of a protected-environment structure such as the Penn State high tunnel cost $1900 ($3.10/ft^2) for a 17 × 36-ft structure (Lamont et al., 2002). However, structural materials of the hoop house cost only $0.95/ft^2, making it possible to give an individual class hands-on experience in greenhouse construction and management.

Benefits of preconstruction activities. Preconstruction activities were critical to the success of this course. We procured all materials and equipment and constructed the hoop house frame before the students started construction. While the TAs could complete the preconstruction work, the TAs were only allotted 10 h (per hoop house) to collect materials and complete initial construction work. Instructors wishing to build hoop houses as a class activity might consider using additional student help (if available) during the preconstruction phase.

Course delivery environment. During construction, we encountered several challenges. The students' first attempt at building the door frames and doors resulted in frames that were not square or doors that were too large for the frame. Therefore, the doors and door frames had to be rebuilt. To overcome this challenge, students were instructed to use a ruler and a level to ensure that the doors were square and were sized correctly. As a result, students gained a better appreciation for the effective use of construction measuring tools.

In addition, some students complained about the weather, which was in high 80s °F, and others lacked personal protective equipment, although they were verbally briefed about the laboratory. Because construction has a risk of serious injury (St. Hilaire and Thompson, 2005), the lack of personnel protective equipment created an unsafe work environment. In response to this, students in the Fall 2007 class were shown photographs of the construction process to better prepare them for construction activities. Instructors also mandated the use personal protective equipment.

Students were varied in their ability to use hand and power tools. Thus, the instructor and TAs provided extensive supervision to the students who were less proficient with hand and power tools. We estimated that one supervisor per five students provided adequate onsite supervision when students were using hand tools and one supervisor per 11 students was sufficient when students were using shovels or rolling out the plastic. A faculty-to-student ratio of one to seven provided enough supervision during a student landscape construction project (St. Hilaire and Thompson, 2005).

Students performed best when supervisors provided onsite instructions for completing specific construction tasks. Our initial expectation was that students would read the laboratory manual before class and complete the laboratory with minimal supervision. However, we noticed that students remained idle when not assigned specific tasks. Therefore, adequate and trained supervision is critical to the success of this course; the TAs must have a thorough understanding of the construction process. This observation supports our current practice in the Department of Plant and Environmental Sciences at NMSU, where future TAs for a class understudy the current course TAs to gain experience.

We believed that the lectures provided students with clear guidance on how to sow seeds uniformly and how to determine the planting depth of lettuce seeds based on time of sowing. Yet, 25% of the students did not sow seeds uniformly (Fig. 2D) or translate the instructions given in the lecture to the practical knowledge needed to interpret seed spacing and planting depth information printed on the back of seed packages. We recognize that directly seeded small seeds such as lettuce have a diminished chance of emergence in a roughly prepared seed bed. However, we believe students would benefit from more practice in sowing seeds.

Environmental monitoring. Protected-environment structures such as high tunnels and hoop houses offer more protection than field production but less than environmentally controlled greenhouses (Spaw and Williams, 2004). Climate monitoring equipment allowed students to observe differences in environmental conditions between the hoop house and the external environment (Fig. 3) while providing them with practical skills in greenhouse instrumentation. Although the outside temperature dropped below freezing during the monitoring period, the higher average night time minimum temperature (3.6 °F) inside the hoop house compared with the outside night time temperature prevented crops from freezing. Therefore, the students' climate data showed how a hoop house extended the growing season beyond Fall 2007.

Diurnal temperature variation averaged 32 °F during fall and winter (Fig. 3). The average maximum temperature consistently exceeded the optimal temperature ranges for growing lettuce 60 to 70 °F (Mason, 2004), and radish (50–65 °F). This implies that the hoop house would have to be vented to ensure optimal crop growth. Thus, the practical application of hoop house instrumentation is to use climate data to determine the optimal strategy for venting the hoop houses. For future classes, we plan to upload the climate data to the course's web site and develop web-based assignments that use the climate data to decide when to vent the hoop house.

STUDENT LEARNING OUTCOMES. Although more students (80%) agreed or strongly agreed that the laboratory supported their learning of greenhouse construction better than the classroom (70%) materials (Table 2), the difference was not statistically different ($P = 0.3479$). These results indicate that students perceived they gained equal benefit from the classroom module as they did from the laboratory activities. Therefore, instructors desiring to integrate experiential learning and practical technological skills into an introductory horticulture class might consider using a hoop house construction module to support classroom instruction.

Experiential learning projects enhance student engagement in the learning process and their motivation to learn (Christy et al., 2000). Student retention in a class or major can be improved if students are motivated. Thus, instructional strategies that enhance experiential learning opportunities for students could help attract students to horticulture careers (St. Hilaire and Thompson, 2005). Because 75% of the HORT 100G are nonmajors, this course could help recruit students to agriculture majors.

The fact that only 43% of the students agreed or strongly agreed that they knew how to calculate fertilizer requirements is not surprising (Table 3). Generally, students are expected to receive more instruction in crop fertilizer requirements in courses beyond the introductory level. For example, horticulture major courses such as plant mineral nutrition and ornamental plant production provide in-depth treatment of plant fertilizer requirements. Given the relatively low student command of how to calculate crop fertilizer requirements, our results suggests that instructors who teach crop fertilizer requirements should consider coupling theory to a real-world application to enhance student understanding of the topic. To further fine-tune the students' skill in fertilizer calculations, we could have assigned a granular fertilizer with a unique N percentage to each of the three hoop houses. We could then ask the students to calculate and compare the application rates for each three hoop houses. This could facilitate group learning while providing multiple opportunities for student to verify their calculations.

Eighty-six percent of students agreed or strongly agreed that they understood the basic techniques of hoop house construction (Table 3). In addition, 89% agreed or strongly agreed that they understood the practical application of building a hoop house (Table 3). During class lectures, we emphasized that hoop houses are low-cost, protected-environment structures that are attractive to resource-limited farmers. We also explained that those hoop houses could be used to extend a crop's production season, allowing farmers to command better prices for the crop. Thus, the students' self-reported data clearly shows that they understood why farmers would consider building a hoop house.

A large percentage of the class (73%) agreed or strongly agreed that climate-monitoring instruments are important for hoop houses (Table 3). We believe more students may have responded positively if the climate data were used rather than simply presented to the students. For example, climate data could be used to determine crops best suited to the hoop house conditions or students could conduct original research on

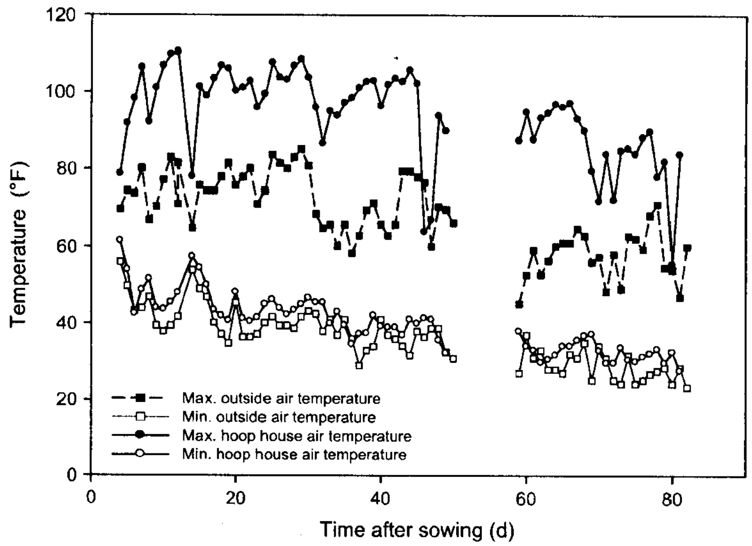

Fig. 3. Maximum (max.) and minimum (min.) outside and inside ambient air temperature of three hoop houses after the hoop houses were seeded on 4 Oct. 2006 [(°F − 32) ÷ 1.8 = °C]. Hoop houses were built by students in the Introduction to Horticulture class (HORT 100G) at New Mexico State University.

Table 2. Responses of undergraduate students when asked questions related to instructional delivery of a course module on hoop house construction. Students (n = 37) were enrolled in the Fall 2007 Introduction to Horticulture (HORT 100G) course at New Mexico State University.

	Response category[z]					
	SD	D	U	A	SA	
Evaluation item	Response (%)					LSMeans[y]
Classroom materials supported my learning of hoop house construction	2.7	2.7	24.3	48.7	21.6	3.8
Laboratory materials supported my learning of hoop house construction	2.7	2.7	13.5	48.7	32.4	4.1

[z]Strongly disagree (SD), disagree (D), undecided (U), agree (A), strongly agree (SA).
[y]LSMeans (least means squares) were based on a Likert scale of 1 to 5 where SD = 1; D = 2; U = 3; A = 4; and SA = 5.

Table 3. Responses of undergraduate students when asked questions related to knowledge of the construction and practical uses of hoop houses, fertilizer requirements for hoop house-grown materials, and the importance of hoop house instrumentation. Students (n = 37) were enrolled in the Fall 2007 Introduction to Horticulture (HORT 100G) course at New Mexico State University.

	Response category[z]					
	SD	D	U	A	SA	
Evaluation item	Response (%)					LSMeans[y]
I understand how to calculate fertilizer requirements of a hoop house crop	13.5	16.2	27.0	32.4	10.8	3.1
I know the basic techniques involved in constructing a hoop house	5.4	0	8.1	56.8	29.7	4.1
I understand the practical application of building a hoop house	5.4	0	5.4	43.2	46.0	4.2
Instruments that measure environmental conditions are important for hoop houses	2.7	0	24.3	35.1	37.8	4.1

[z]Strongly disagree (SD), agree (A), undecided (U), agree (A), strongly agree (SA).
[y]LSMeans (least means squares) were based on a Likert scale of 1 to 5 where SD = 1; A = 2; U = 3; A = 4; and SA = 5.

how to vent a hoop house properly to maintain inside temperatures within a certain range. We originally planned to restrict all aspects of the hoop house module to the undergraduate course; we now envision using the hoop houses in a graduate class on Instrumentation in Agriculture (HORT 620) to expose graduate students to climate data acquisition.

Conclusions

Although the undergraduate students had no experience in engineering design and construction, class evaluations clearly show that the module enhanced their understanding of hoop house construction. The students' eagerness to sow the seeds immediately upon completion of construction is a testimony of their engagement with the experiential learning opportunity. Based on the utility of the hoop house construction in teaching core HORT 100G topics, as well as ancillary topics such as climate data acquisition, we have permanently incorporated the hoop house construction module into the HORT 100G class. Furthermore, hoop houses offer an inexpensive way to teach greenhouse-related topics and research strategies for venting structures with limited environmental controls and to demonstrate how to acquire climate data from protected-environment structures.

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