Use of a Portable Sawmill for Forestry Instruction

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Abstract

The Arthur Temple College of Forestry and Agriculture at Stephen F. Austin State University in Nacogdoches, TX, has implemented an experiential learning exercise to improve student learning related to the forest products industry. During the week-long sophomore- or junior-level course Harvesting and Processing, forestry students tour multiple wood products facilities such as sawmills. These mills use complex technologies to maximize the lumber produced from each log, and students were having difficulty understanding the underlying concepts. As part of this course beginning in 2012, students began working in teams to estimate the lumber that will be recovered from a log and then actually sawing their own log using a portable sawmill. Since the introduction of this experiential learning project, student comments, instructor observations, and an increase in the mean course grades suggest that the sawmill activity is not only popular among students, it also allows for a fun, competitive, and engaging way to prepare future natural resource managers for their careers.

Core Ideas

- Incorporating a sawmill exercise allowed students to develop log scaling and grading solutions.
- Working in teams led to collaborative problem solving.
- The sawmill exercise mimics larger-scale practices in industrial facilities.

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Universities play an important role in preparing natural resource professionals as individuals capable of solving complex problems (Bullard et al., 2014) whose education must be relevant, rigorous, and build relationships (Bullard, 2015). Gaps between skills desired by employers and those possessed by graduating undergraduate students have been identified, and include collaborative problem-solving and written and oral communication (Bullard et al., 2014; Sample et al., 1999). Current natural resource education needs to "provide opportunities for students to acquire the knowledge, skills, abilities, and behaviors that clearly reflect employer, societal, and environmental needs" (Layton et al., 2011). Natural resource managers learn problem solving experientially, but must blend this learning with critical thinking and other skills developed through a variety of instructional modes (Millenbah and Millspaugh, 2003). To solve complex and difficult solutions to natural resource problems, students need to work in interdisciplinary teams to develop and implement management plans (Newman et al., 2007). Gill (2004) identified four challenges for natural resource professionals including politicization of resource management, interdisciplinary collaboration, adaptive resource management, and adaptive resource policy-making. Students drawn to forestry tend to have a converging learning style that is characterized by a preference for active experimentation (Kolb et al., 2001), which suggests they are well-suited to experiential learning methods.

Undergraduate education for the Bachelor of Science in Forestry (BSF) in the Arthur Temple College of Forestry and Agriculture (ATCOFA) at Stephen F. Austin State University in Nacogdoches, TX, focuses on management for forest products, wildlife, water quality, and recreation. A 6-week-long field station focused on experiential learning is taught after the sophomore year. The term "field station" is used rather than the more traditional "field camp" because many of our students were military veterans in the late 1970s and equated "field camp" to "boot camp," which produced an undesirable association for some of them. Field station is comprised of six separate 1-credit-hour courses (Table 1), which are taught in a different order each year depending on faculty availability. A different group of faculty teaches each course. Although the courses do not build on each other, they do build on other pre-requisites in the curriculum, and are key experiences needed for later course work. During field station, intensive experiential instruction in practical

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Abbreviations: ATCOFA, Arthur Temple College of Forestry and Agriculture; BSF, Bachelor of Science in Forestry.

Table 1. Breakdown of the 6-week-long field station into its six component courses. Each course is 1-credit-hour and is taught for a single week by a different group of faculty from the other courses.

Number	Course name	Major exercises
FOR 310	Field Silviculture	Stand examinations and silvicultural treatment observations
FOR 323	Land Measurement	Boundary delineation, forest inventory analysis plot measurements, pond design, global positioning system and compass exercises
FOR 325	Timber Cruising	Point and plot sampling of forest stands
FOR 329	Harvesting and Processing	Mill tours and sawmill exercise
FOR 335	Non-Timber Resources Management	Recreation assessments, canoe trip, camping exercise
FOR 336	Field Wildlife Techniques	Capture and measurement of mammals, birds, and herptiles

applied field methods are the primary focus so that forestry students learn skills to solve problems forest resource managers face on a daily basis (Unger et al., 2014).

The objective of this article is to describe the implementation of a new experiential learning exercise into the Harvesting and Processing course during field station. We present 6 years of course grade data to assess the student learning outcomes of incorporating a sawmill exercise.

MATERIALS AND METHODS

Field Course

Today's forest products industry solves complex problems with an array of technological applications (Shmulsky and Jones, 2011). Prior to the field station, students take a 2-credit-hour course on wood technology divided evenly between laboratory exercises on wood anatomy and identification and lecture sessions on the forest products industry and the technologies it employs. During the Harvesting and Processing course at field station, students have the opportunity to observe the full process of creating forest products, from in-woods harvesting operations to sawmill tours. Harvesting demonstrations include whole tree cutting with a feller-buncher that cuts standing trees. A skidder then carries the trees to a logging deck, where a processer delimbs the trees, cuts them to length, and loads them on a log truck for transport to a mill.

A number of different types of mills are toured, including facilities that produce dimensional sawtimber, paper, oriented strand board, and other forest products. A key feature of the sawmill tours are systems that use optimization technologies to measure the size of logs (i.e., scale them) and produce the most desirable products from each log (i.e., optimize them) (Gjerdrum, 2012; Rinnhofer et al., 2003; Shmulsky and Jones, 2011). Optimizations of how each log will be sawn into boards of varying lengths, widths, and thicknesses, along with the portions of the log that will not be used to make boards, are displayed on a computer screen that is visible to the students. In a fully mechanized sawmill, once boards are cut they are automatically graded using a variety of technologies (Bharati et al., 2003; Conners et al., 1992; Kline et al., 2003) and sorted by grade for distribution and sale. Lumber grades are related to the quality of the boards, and impact their value. For sawmills without automatic graders, the lumber is visually graded and sorted by experienced personnel. For each mill, students consider value-added products, markets for the products, competitive products and strategies, safety programs and environmental issues, and make recommendations for improvements. This learning is assessed through quizzes and memoranda they prepare and submit detailing each of these items.

Despite prior lectures on how scaling, optimization, and grading technologies function, and the students' opportunity to witness them in operational use, a lack of understanding was evident on various assignments given to assess student learning before 2012. Essentially, watching these activities in mills, or hearing about them in lectures, were passive modes of instruction that did not result in sufficient learning (Joplin, 1981). Because a deficiency was perceived in student learning, a new experiential learning exercise was incorporated into the Harvesting and Processing course during field station. For the culminating exercise on the last day of the week-long course, students now operate a Wood-Mizer portable sawmill to produce boards from logs (Fig. 1). Student learning objectives for the sawmill project include applying log and lumber grading techniques, demonstrating proper safety techniques needed to operate a sawmill, calculating the volume and dimensions of lumber that can be obtained from a log, and creating strategies to increase the quantity and quality of lumber sawn from a log. These learning objectives fit several key areas identified in a comprehensive, survey-based study of the BSF curriculum that were identifed as important but where student performance was perceived as lacking (Bullard et al., 2014), including "apply analytical skills to measure and predict" and "provide consumable forest products for society."

Sawmill Exercise

Log Scaling

Pine (*Pinus* sp.) or oak (*Quercus* sp.) logs are donated by ATCOFA alumni and are assigned to teams of four to eight students, depending on the size of the class. Teams are required to develop a cutting solution that will optimize the volume of recoverable lumber from each log. Larger boards are preferable to smaller boards, and defects such as knots and curvature of the log must be evaluated, adding complexity to this exercise. Often this involves a substantial amount of trial-and-error, along with the sorts of discussions and disagreements among group members that are a desirable component of the collaborative learning process as described by Cog's ladder (Charrier, 1972). After the final cutting solution is approved by instructors, the cutting plan

Fig. 1. The Wood-Mizer LT20 TR sawmill being operated by a student, as other students look on to ensure safety protocols are being correctly followed.

is drawn using a marker on the end of the log (Fig. 2). The cutting solution must account for "kerf" (the wood that will be lost as sawdust due to the width of the sawmill blade). The students must scale their logs, which means they must estimate the volume of lumber that will be obtained based on measurements of the length and diameter of their logs. Although this sounds simple in theory, in practice it quickly becomes very complex because logs taper, are often not straight (Fig. 2), contain various defects, and may contain internal rot (Fig. 3) that is not obvious from the external appearance (Avery and Burkhart, 2011; Ham et al., 1997). To scale a log, students apply three different log rules (Doyle, Scribner, and International 1/4 inch; formulae that predict lumber volume based on log length and diameter). They then develop a projected board volume to be cut by summing the total volume of all the boards they expect to saw based on their cutting solution. Because the logs are then actually cut by the students into lumber, they are able to compare their projected lumber yield to the actual yield, which is termed "recovery." Loss of recovery may be due to incorrect measurement of the curvature of the log, not having the log level during cutting, or not following the prescribed cut marked on the log.

Log Grading

After scaling and before sawing their logs, the students grade their logs to predict the quality of lumber that will be sawn. There are hundreds of log grading systems available in the literature (e.g. Campbell, 1962; Rast et al., 1973), but applied publications from state extension agencies offer the best practical guidance to students. These publications generally include illustrations and definitions of technical terms with which students may be unfamiliar, and are designed to be used quickly in the field. For hardwood logs a handbook by Taylor (2009) is used, whereas for pine logs an adaptation of the Clark and McAlister (1998) tree grading system is used. Log grades are recorded, and a predicted distribution of lumber grades is generated from the log grade.

Safety

Immediately before logs are sawn, safety procedures are outlined including the proper use of personal protective equipment including earplugs, an industry certified hard hat, an orange or yellow safety vest, and boots. Instructors trained in first aid demonstrate proper use of the sawmill, describe potential mistakes that could result in injury, and constantly supervise the sawmill throughout the exercise. Beyond instructor supervision, a culture of safety (Cohen, 1977; Reason, 1993) is discussed and emphasized whereby the students are responsible for their own safety and the safety of their peers. While one group is cutting, another group is responsible for monitoring safety. The safety monitoring group is vigilant for any violations of the safety policy, and has the authority to shut the operation down until corrective action has been implemented. If the safety monitoring group misses any significant violations, then this group can have points deducted from their grade.

Sawing

A portable sawmill is essentially a large band-saw that feeds through a log. Portable sawmills are commercially available and can be set up adjacent to or on sites that are being actively logged. These mills are easy to relocate by towing them behind a standard pick-up truck with a hitch. Once the lumber is cut, boards are typically either kiln or air dried (Blackwell and Stewart, 2003). The ends of the boards are treated with an end-sealant to keep them from splitting during air drying. A complex combination of factors contribute to the quality of the cut, such as blade speed, blade tension, blade thickness, blade width, tooth design, and tooth spacing (Blackwell and Stewart, 2003). Sawblades are manufactured from high quality steel essential to good performance for durability, resistance to wear, and ability to keep the tension on the blade (Kays, 2007). Faster speeds of the sawblade increase the chip size and slower speeds cause sawdust spillage between the blade and the wood, which can result in wavy sawing (Blackwell and Stewart, 2003; Frankson, 1977). Students are able to observe the effects of the combination of these factors on the quality of their cuts as they saw.

Logs are loaded onto the sawmill base, either with a tractor or by rolling the logs up a ramp. Once in place, the logs are turned to the desired position and locked in place using a log peavey as a lever (Fig. 3). Students can then adjust and position the log for optimum cutting, both in terms of thickness and being square. Metal chocks at the back of the

Fig. 2. (A) A hardwood log with evident curvature, which makes estimating the volume of the log and the volume of boards that will be sawn difficult. (B) The cutting solution drawn onto the smaller end of a log. As is evident to the left side, this group had difficulty cutting their boards as initially planned, as they had not accounted for kerf (the wood that will be lost as sawdust due to the width of the sawmill blade) correctly.

Fig. 3. (A) A log held into place on the bed of the sawmill and locked in place with a lever. (B) A log squared up into a cant (square section of lumber) for optimal cutting of boards. (C) Internal defects in logs can be detected from both log grading and from cutting the log. (D) Boards cut from a hardwood log are treated with preservative and ready for grading.

Fig. 4. Students posing for a photograph with their boards after they have been sawn and graded. Universities in Texas all have characteristic hand signs students and alumni proudly display, hence the "Axe 'em Jacks" symbol to reflect the school mascot, the lumberjacks.

log keep it in place. Once the log is oriented correctly, the sawmill blade is started, and the critical first cut is made on the log. A power motor under control of a student advances the sawmill carriage along the log. Once the slab (edge board with one wide curved side with bark) is cut, the process is repeated for the next slab or board. The log may be turned between cuts in order to optimize recovery of the highest quality sawtimber possible. There are enough boards cut per log that each student is able to make at least one cut. While cutting, care must be taken to avoid turning the log, which can cause both a badly cut board and injury. Once the boards are processed, their edges can be squared up using the sawmill, then the ends of the boards are treated with a sealant to reduce splitting on the board ends. Students are diligent in carefully cutting the boards, as each of them is allowed to keep one or more of the boards from their log, giving them a sense of ownership (Fig. 4).

Board Scaling and Grading

The recovery is compared to predicted estimates. Each group of students then grades their boards and estimates recovery based on their optimization estimates. Losses to projected recovery include difficulty in measuring sweep and taper and incorrect cuts on the sawmill, among other factors. Boards are graded using Taylor (2009) from FAS Premium to #3 Common. The grading process determines the expected economic value of each board based on clear face, knots, decay, and any discoloration staining that may be present.

Assessment of Student Learning

Student learning during Harvesting and Processing is evaluated via a variety of different exercises requiring student feedback. The grade allocation for Harvesting and Processing was altered to incorporate the sawmill exercise. Before the exercise it was 78% for the memo, 16% total for four quizzes, and 6% for participation. After implementing the exercise it was 60% for the memo, 15% total for three quizzes, 5% for participation, and 20% for the sawmill exercise. Quizzes are short answer and are administered nightly during the course, typically covering the day's activities. Participation scores are subjective, but are primarily based on attendance.

The memo is an 8- to 10-page, double-spaced, comprehensive document including discussions of each of the course's tour sites. A grading matrix is provided to the students at the beginning of the course. For each site, a detailed list of eight categories of required information is provided. Categories include basic company information, their source of raw materials, how the company makes a profit, the markets for their products, the nature of their competitors, competitive strategies, safety programs and environmental issues, and recommendations for improvements.

The sawmill exercise is graded based on submitted written deliverables. Five categories are required.

1. A drawing of log length and diameter, with cuts drawn and labeled.
2. Log volume in Doyle, International ¼ Inch, and Scribner Decimal C.
3. Volume and dimensions of boards and lumber actually milled.
4. Log grade, and grade of each board.
5. A brief description of the lumber recovered, and any challenges encountered.

The written reports for the sawmill exercise that were submitted in 2015 were used to prepare Tables 2 and 3 documenting student results.

Student grades were recorded by assignment in 2008 and 2011 prior to implementation of the sawmill exercise, and in 2012–2015 following implementation of the sawmill exercise. In 2014, field station was transitioned from being held the summer after the junior year to the summer after the sophomore year. This was done to improve the students' opportunities to take part in internships once they had completed more coursework following their junior year. Thus, two field stations, one sophomore, and one junior, were taught in 2014.

Grade data were analyzed in SAS 9.2. (SAS Institute, Cary, NC) using PROC GLM to complete one-way ANOVAs. Two ANOVAs were performed using an alpha of 0.05. First, pre-sawmill-exercise overall course grades (two classes) were pooled and compared with overall course grades following implementation of the sawmill exercise (five classes) to test the hypothesis that the sawmill exercise resulted in improved grades as a surrogate for student learning. Second, all seven classes (again, two were held in summer 2014) were compared to determine if overall course grades differed between each class. Because this ANOVA was significant ($p < 0.0001$), a Tukey-Kramer post-hoc test was performed.

RESULTS

All student-collected data on logs and boards were summarized for the 2015 field station (Tables 2 and 3). Nine hardwood logs ranging from 9.5 to 15.0 inches in diameter and 8.0 to 8.4 feet in length were sawn, one per group (Table 2).[1] Although students projected recovery of 7.3 boards per log on average, they were able to saw only 5.4 boards on average. Most of the predicted boards that they were unable to cut were one inch wide boards near the face or edge of the log (Table 3). The three log rules used produced an estimated mean 38.9 board-feet of lumber to

[1] English units are used in this article because the forest products industry in the United States uses almost exclusively English units.

Table 2. Student-collected data for nine logs sawn on the Wood-Mizer portable sawmill in 2015. Lower numbers for log grade indicate a higher quality log. Doyle, Scribner, and International 1/4 Inch are three different log scaling methods that produce different estimated lumber volumes from a log of a given size. Recovery is the volume of boards actually sawn as compared to pre-sawn estimates based on log size and shape.

Log	Species	Diameter inside bark	Length	Log grade	Boards per log: Estimated	Boards per log: Actual	Estimated yield: Doyle	Estimated yield: Scribner	Estimated yield: Int. 1/4 inch†	Predicted yield	Actual recovery
		inches	feet				board-feet				
1	White ash	9.5	8.0	3	6	4	12	15	18	37.2	28.0
2	Sweetgum	9.5	na†	na	7	5	12	15	18	32.1	25.3
3	White ash	10.0	8.0	2	7	6	18	30	30	41.0	38.6
4	White ash	13.1	8.4	3	10	8	41	50	55	na	65.3
5	White ash	12.0	8.0	3	7	5	41	50	55	102.0	74.0
6	White ash	13.9	8.0	3	8	5	40	50	55	67.8	56.0
7	White ash	11.5	8.0	3	5	4	24	24	20	na	26.7
8	Water oak	10.0	8.0	3	5	4	32	40	35	na	36.0
9	White ash	15.0	8.2	2	11	8	85	90	95	114.0	99.8
Mean	na	11.6	8.1	2.8	7.3	5.4	33.9	40.4	42.3	65.7	50.0

† Int. 1/4 inch, International 1/4 inch; na, data not available.

Table 3. Estimated and actual board dimensions (inches) and grades for each board sawn from the nine logs described in Table 2 from field station 2015. Board quality decreases in the order FAS Premium > Select > #1 Common > #2 Common > #3 Common > Fuel Grade.

Log	Boards per log: Estimated	Boards per log: Actual	Board grade	Log	Boards per log: Estimated	Boards per log: Actual	Board grade
	inches				inches		
1	2 × 6	2 × 6	FAS Premium	6	1 × 2	2 × 4	#2 Common
	2 × 6	2 × 6	FAS Premium		2 × 8	2 × 8	#1 Common
	2 × 6	2 × 6	FAS Premium		2 × 12	2 × 12	Select
	1 × 6	1 × 6	#1 Common		2 × 12	2 × 12	#1 Common
	1 × 5	NR†	NR		2 × 10	2 × 6	#2 Common
	1 × 4	NR	NR		1 × 8	NR	NR
2	1 × 6	1 × 6	#2 Common		1 × 4	NR	NR
	1 × 6	1 × 6	#2 Common		1 × 6	NR	NR
	2 × 6	2 × 6	#1 Common	7	2 × 6	2 × 4	FAS Premium
	2 × 6	2 × 6	#1 Common		2 × 8	2 × 8	#1 Common
	2 × 6	2 × 4	#2 Common		1 × 8	1 × 8	#3 Common
	1 × 4	NR	NR		1 × 6	1 × 8	#3 Common
	1 × 4	NR	NR		1 × 4	NR	NR
3	1 × 4	NR	NR	8	1 × 4	NR	NR
	1 × 6	1 × 6	Select		2 × 6	2 × 8	#1 Common
	2 × 8	2 × 8	Select		2 × 8	2 × 8	#1 Common
	1 × 10	1 × 10	Select		2 × 10	2 × 10	FAS Premium
	2 × 8	2 × 8	Select		1 × 6	1 × 6	#1 Common
	1 × 6	1 × 6	FAS Premium	9	2 × 6	2 × 8	Select
	1 × 4	1 × 4	#2 Common		1 × 8	1 × 10	Select
4	2 × 6	2 × 6	Select		2 × 10	2 × 12	FAS Premium
	2 × 6	2 × 6	Select		2 × 14	2 × 12	FAS Premium
	2 × 6	2 × 6	Select		2 × 14	2 × 14	Select
	2 × 6	2 × 6	Select		2 × 14	2 × 14	Select
	2 × 6	2 × 6	Select		2 × 10	2 × 10	Select
	2 × 6	2 × 6	Select		1 × 10	NR	NR
	2 × 10	2 × 10	Select		1 × 8	1 × 8	Select
	1 × 6	1 × 6	Select		1 × 6	NR	NR
	1 × 4	NR	NR		1 × 4	NR	NR
	1 × 4	NR	NR				
5	1 × 6	NR	NR				
	2 × 8	2 × 8	#1 Common				
	2 × 12	2 × 12	#1 Common				
	2 × 12	2 × 12	Select				
	2 × 10	2 × 6	#2 Common				
	1 × 8	1 × 4	Fuel Grade				
	1 × 4	NR	NR				

† NR means that the board was not able to be recovered or sawn as planned by the students.

Table 4. Student-collected data for 21 logs sawn on the Wood-Mizer portable sawmill from 2013 to 2015. Doyle, Scribner, and International 1/4 Inch are three different log scaling methods that produce different estimated lumber volumes from a log of a given size. Recovery is the volume of boards actually sawn as compared to pre-sawn estimates based on log size and shape.

Log diameter	Doyle	Scribner	International 1/4 inch	Projected recovery	Actual recovery	Difference
inches	board-feet					
17	85	90	95	114	100	14
13	41	50	55	71	65	6
12	18	30	30	41	37	4
12	32	40	35	32	36	-4
10	12	15	18	37	32	5
10	12	15	18	37	28	9
9	20	24	20	24	27	-3
14	41	50	55	102	74	28
12	32	43	45	53	53	0
16	61	70	75	87	85	2
11	32	40	45	42	40	2
14	56	60	65	77	80	-3
13	41	55	50	65	68	-3
12	32	43	44	56	53	3
13	36	47	48	60	61	-1
11	26	38	41	48	52	-4
14	50	60	65	73	73	0
11	25	34	37	45	51	-6
13	41	56	55	62	62	0
13	25	32	35	48	52	-4
14	41	50	55	60	60	0
Mean: 12.6	36.1	44.9	47.0	58.8	56.6	2.1

Table 5. Grade means, with standard errors in parentheses, for the Harvesting and Processing course before and after implementing the sawmill exercise in 2012. Classes noted with different Tukey Group letters had different mean course grades ($p < 0.05$).

Year	Cohort	Students numbers	Sawmill exercise	Course grade	Tukey group
2008	Junior	27	–	79.9 (1.86)	A
2009	Junior	na†	–	na	
2010	Junior	na	–	na	
2011	Junior	19	–	87.2 (2.14)	BC
2012	Junior	27	93.9 (1.32)	84.4 (1.44)	AB
2013	Junior	44	99.3 (0.38)	94.2 (0.47)	DE
2014	Junior	37	99.9 (0.13)	90.4 (1.31)	CD
2014	Sophomore	15	100.0 (0.00)	94.8 (2.80)	CDE
2015	Sophomore	47	95.0 (0.66)	95.3 (0.52)	E

† na, data not available.

be sawn per log, whereas the students estimated a mean of 65.7 board-feet per log, or 169% that amount. The students tended to overestimate yield by failing to account for curvature of the log (Fig. 2), underestimating kerf (Fig. 2), and underestimating the amount of loss on the slabs when squaring off their log into a cant (square section of lumber) (Fig. 3). They actually recovered a mean of 50.0 board-feet per log, which was only 76.1% of what was predicted from the boards they planned to cut, but slightly more (128.5%) than what was predicted with the three log rules. Across all nine logs, all possible board grades were observed, allowing students to both experience the grading procedure, and see real-world examples of each category.

The 2015 data represented one of the poorest performances on the log scaling portion of the assignment over the last several years. When data from 2012 through 2015 are considered, the students performed considerably better on average, with only a 2.1 board-feet per log, or 3.7% mean overestimate in projected recovery compared with actual recovery (Table 4). The students recovered 96.3% of the volume that they predicted when averaged across 21 logs, although there were a small number of groups that made considerable errors (i.e., 102 vs. 74 board-feet) between their prediction and boards actually sawn.

Conversations with students during the sawmill exercise, and a post-field station interview with them conducted each year by the dean and associate dean (neither instructors in the course during this study period), provide strong qualitative evidence supporting the value of the sawmill exercise. No negative student comments have been received regarding the exercise. Positive comment examples from student evaluations include "Really enjoyed this class; especially making our own boards," and "Enjoyed working with wood mizer." These qualitative data are limited in nature, as these interviews focus on all of field station, whereas the sawmill exercise is only one component of one of six courses.

The quantitative information is derived from the overall course grades pre- and post-implementation of the sawmill exercise. This is generally one of the highest graded assignments of the week, as students seem to appreciate the experiential nature of the assignment. As a result, it has always received mean grades in the A range (>89.9%), which has improved the overall course grades from a class-size weighted mean of 82.9% (grade of B) for the 2 years of data prior to implementing the sawmill exercise, to a class-size weighted mean of 92.2% (grade of A), a gain of almost 10 points ($p < 0.0001$). Examining the overall course grades of seven classes and treating each class as a separate group reveals a more complicated story (Table 5). The 2008 overall course grades were lower than 4 of the 5 years after implementation of the sawmill exercise ($p < 0.05$). The 2011 group was only lower than 2 of the 5 years after implementation ($p < 0.05$), and was not statistically different from the other 3 years ($p > 0.05$). Grades may be correlated to learning on some levels (Anaya, 1999), but we recognize assignment grades are not necessarily an ideal tool to evaluate the achievement of learning objectives (Johnson, 2006).

DISCUSSION

This exercise has become one of the most popular activities at the ATCOFA summer field station. Students use experiential learning to understand how important optimum value recovery is to the profitability of the forest industry. Student grades on this exercise are typically excellent, because they take ownership of the task, become somewhat competitive among groups, and rise to the challenge of having the best recovery. Grades on the sawmill exercise typically have a mean of 98.5%, compared with a mean of 90.5% on the other assignments given during the course across all 4 years of post-implementation data. Students also gain a much deeper appreciation of sawmilling through this exercise. They take great pride in making their own lumber. Although few of these students are likely to be sawyers in a sawmill, as natural resource managers understanding the processes in producing forest products such as sawtimber is critical for a successful career. These outcomes are almost entirely consistent with the nine characteristics of experiential learning identified by Joplin (1981), with the sole exception of the group nature of the exercise.

Natural resource students are attracted to forestry for the potential to work outdoors and respond to iterative learning (Bullard et al., 2014). Three elements essential to the natural resource and forestry manager for the future include maintaining relevance, improving rigor, and building relationships (Bullard, 2015). The sawmill exercise included a number of elements that helped students develop relevant skills, including communication of the results via a written report and the teamwork required to complete the project safely. By incorporating additional steps such as documenting the dimensions of the boards to cut prior to sawing, the log grading, and the board grading, the sawmill exercise improved the rigor of the Harvesting and Processing course. A core focus of the Harvesting and Processing course is in building relationships, which includes visits to mills to view hardwood lumber grading and discuss the experience of the sawmill employees.

Students were highly engaged in the final sawmill project and carried this interest over into question and answer sessions during mill tours. By working in groups, the students encouraged safety, participation, and pride in their accomplishment of the final boards cut (Fig. 4). As the sawmill exercise expanded by adding both grading of the logs and the boards cut, overall grades for the field station Harvesting and Processing course increased. The exercise reinforced the need to make good management decisions when renewing a forest that has been harvested. By viewing several mills ranging from using wood flakes for oriented strand board, to dimension lumber, to wood chips for paper making, to use of wood residue for biomass plant fuel, reinforced the role of the forester in society, emphasizing the range and variety of career opportunities (Bullard et al., 2014). Overall, this experiential learning exercise has improved student learning in this course as supported by overall course grade data, and provided students with a tangible memento of that learning in the form of a board that they have sawn.

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