Development and Assessment of a Prototype as an Innovative Method for Teaching Agricultural Machinery

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Abstract. *An educational variable-rate application (VRA) sprayer was developed and laboratory tested at the University of Seville (Spain). It was designed and built during 2009 by the undergraduate engineering students in a Precision Agriculture course and used as a teaching model in an Agricultural Machinery course during 2010. The first stage involved mounting all the instrumentation, sensors, and the hydraulic system on a metal platform. The second stage involved mounting a DGPS receiver, flowmeter, automated application control system, and all necessary electrical connections to the platform. Preliminary calibration tests of the equipment at a constant speed of 0.375 m s^{-1} (1.35 km h^{-1}) showed good performance for pressure (kPa) and application rate (L ha^{-1}) ($R^2 = 0.998$, $p < 0.001$). To evaluate the teaching method based on the prototype, a short-answer assessment test was conducted consisting of ten multiple-choice questions, each with one possible correct answer. Data were analyzed using analysis of variance (ANOVA). The factors were the teaching method (TM), repeated course (R), and attended theory (AT). In addition, the effect of a covariate (number of times a student repeated the course) in the factors was controlled with an analysis of covariance (ANCOVA). The effect of teaching method was significant for the score on the VRA sprayer questions (SPS) variable and the score on the conventional sprayer questions (SCS) variable ($p < 0.001$ for both). The average success for students using the prototype sprayer was 86%, compared to 60% for those using a conventional sprayer. The total cost of the VRA prototype sprayer was 40% less than the cost of retrofitting a conventional sprayer with precision agriculture equipment. Since the students were engaged in their own learning, they maintained a high level of enthusiasm throughout the course when utilizing the VRA prototype sprayer. It has proved to be a complementary and beneficial alternative for improving the students' education in the Agricultural Machinery course.*

Keywords. *Application technology, Education, Precision agriculture, Teaching models.*

Since the early 20th century, institutions such as ASABE in North America and CIGR (Commission Internationale du Genie Rural) in Europe have endeavored to further the interest in agricultural engineering, promote research, improve teaching methods, and better correlate these activities with those of the U.S. and European Departments of Agriculture. Nowadays, higher education is experiencing phenomenal improvements as a consequence of new teaching methodologies that have been shown to be more appropriate for the needs of today's students and industry. Improving teaching effectiveness is a strategic focus in higher education to nurture innovation (Campbell and Colbeck, 1998; Dym et al., 2005). The teaching of instrumentation, control systems, electronics, and automation in the discipline of agricultural engineering has paralleled the engineering developments in agriculture. Dynamometer technology illustrates the developments in agricultural engineering. Dynamometers apply loads to a running engine, allowing engineers to determine the engine's torque, horsepower, safety, and inefficiencies or failure conditions (Davidson and Chase, 1908).

Teachers and researchers are tasked with developing modern teaching techniques that instill motivation for learning engineering and applying the progress that occurs in industry, such as technological advances, globalization, etc. A recent study confirmed that students are encouraged to learn by classroom environments that incorporate interaction, discussion (particularly for higher-grade point average students), hands-on activities (particularly for lower-grade point average students), and assignments that demonstrate a clear connection to their prospective profession (Mankin et al., 2004).

Future courses in Agriculture Machinery should not only focus on the transmission of knowledge but also provide tools that allow students to direct their own learning. During the last decade, university programs in agricultural engineering in Europe faced profound challenges, including decreased student enrolment, reduced prestige, and declining funding (Briassoulis et al., 2001; USAEE-TN, 2006). This challenging situation provided the motivation for improving the educational methodologies, which will hopefully increase

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student enrolment, enhance prestige, and increase funding for agricultural engineering universities.

Fink (2003) observed that the typical methodology for teaching a course is to generate a list of eight to twelve topics pertaining to the subject and then create lectures for each topic. The addition of midterm and final exams completes the course. The list of topics may come from the teacher's experience with the subject or from the table of contents of a textbook. This particular formulation of the course design process has a number of attractive features for teachers (simple, rapid, efficient, etc.). However, Fink (2003) argued that this process is based on information organization, which tends to induce superficial learning and often does not precipitate subject retention. As an alternative, collaborative learning is effective and convenient when integrated into a course that focuses on the learner. The concept of actively involving the students in using a prototype is to teach innovation and to cement the learning process. Sternberg and Horvath (1995) searched for a middle ground between the current definitional model and the *ad hoc* model of teaching expertise, which are prevalent in educational research. They argued that a well-defined standard of teaching expertise, which all experts and non-experts met, does not exist. They then proposed a prototype view that provides a new paradigm of teaching expertise that incorporates standards in which not every experienced practitioner is an expert. This allows for variability in the prototype profiles. Their rationale for using a teaching prototype distinguishes teachers who are experts from those who are merely experienced at teaching students. Prototypes clarify a teacher's pedagogical proficiency.

The use of prototypes in engineering courses is relatively rare, or at least not a fundamental part of the subject. These courses usually rely on deductive learning by focusing on theoretical aspects of the subject. However, when prototypes are applicable, they facilitate student interest, especially in subjects that involve experimental components, such as agricultural machinery. Schuguresnsky et al. (2000) involved student participation by building a scale greenhouse. Experiments were then performed within the model greenhouse rather than in a traditional laboratory. Slocombe et al. (1990) designed a teaching prototype to demonstrate which pesticide application technology resulted in fewer application errors. This prototype was included in educational programs to ensure greater operator understanding of application equipment design and functionality.

An important motivation in the use of prototypes is economic. How the prototypes are linked to conventional lecture-based teaching is therefore important (Wellstead, 1990). The approach should allow greater autonomy for students to carry out tests in subjects that are otherwise explained as theory. However, the use of a conventional sprayer with a tractor would require the presence of university staff for safety and security. In addition, agricultural engineering students must also learn the basic components of these devices (Dickinson et al., 2007). Denson (2005) created a curriculum development team that prepared drafts of curriculum modules to oversee the design and engineering of a prototype 1/8-scale model row-crop tractor, which was used to simulate preventive maintenance and retrofitting activities. This prototype was implemented in agricultural tractor safety training programs for youth who work in production agriculture in the U.S.

The cost of prototypes in an Agricultural Machinery course can be justified by the acquisition or rental cost of new machinery, the cost of travel to farms, the risk of adverse weather, the rapid improvements in technology, and the difficulty of using farms not located on campus. In addition, applying prototypes in the teaching process facilitates an understanding that is not possible with paper or a computer screen (Ruiz Estrada, 2009) because the teaching process is divided into classroom teaching (theory and problem solving) and a practical section. With the addition of prototyping, knowledge, key points, and difficulties can be addressed and resolved immediately. In this way, the students proceed step by step from easy material to difficult concepts, steadily mastering the course knowledge. There is a base knowledge level for the course. Beyond the basics, the students are encouraged to explore in-depth knowledge, ask question, analyze, and solve problems to maximize their own potential and improve their comprehension.

The main objectives of this educational experiment were (1) to develop a variable-rate application (VRA) sprayer prototype and (2) compare teaching using the prototype with traditional teaching in an Agricultural Machinery course.

Materials and Methods

Sprayer Construction and Calibration

An automatic laboratory sprayer with a 15 L capacity was designed and developed by 20 undergraduate students during a Precision Agriculture and Natural Resource Engineering course. Figure 1 shows the prototype. It consisted of a metal platform on which the instrumentation, sensors, and the complete hydraulic system were mounted. The sprayer was equipped with a compressed air system (using a bottle of compressed air or inert gas) at pressures ranging from 0 to 500 kPa. The boom was divided into four sections, each containing one nozzle. The four flat-fan nozzles (Teejet XR11040, Spraying Systems Co., Wheaton, Ill.) were on 50 cm spacing. Each nozzle was controlled by a solenoid-actuated valve (model Masotti, Elttromotori S.R.L., Ischitella, Italy) that was energized by a 12 VDC source, allowing each boom section to be controlled independently.

The sprayer has two configurations: fixed and unfixed. The fixed configuration is for laboratory work. The boom and GPS antenna are detached from the system and travel along a 1.5 m rail to simulate tractor movement while the rest of the system remains stationary. A 12 VDC motor moves the boom and antenna along the rail by driving a pinion and roller chain. A limit switch stops the motor before the boom impacts the rail's end support. By selecting the pinion diameter, the boom's linear velocity can be regulated. In the unfixed configuration, the boom and GPS antenna are attached to the metal platform and the whole system moves as one unit. The unfixed configuration is used to move the system outside of the laboratory, but only for short distances. In this case, the electric motor no longer moves the boom, and the boom is attached to the metal platform. An important aspect in both configurations is the GPS antenna position. In the fixed configuration, the GPS antenna is mounted above the boom, which allows both to be moved by the motor. In the unfixed configuration, both are mounted on the metal platform.

A DGPS receiver, flowmeter, fluid control system, application control system (AgGPS EZ-Boom 2010), and all

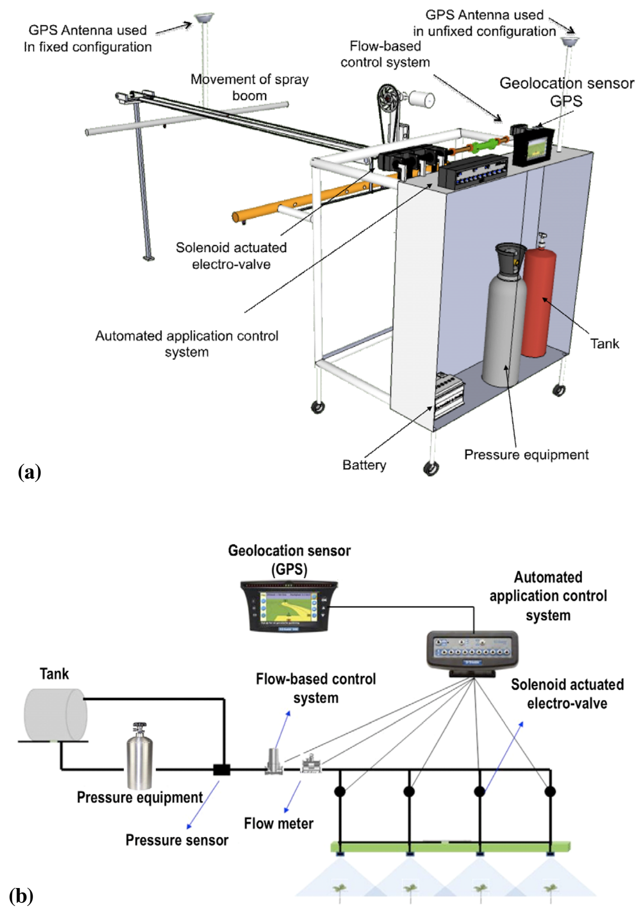

Figure 1. Prototype built for teaching and evaluating the learning process: (a) diagram of the VRA sprayer prototype with two possible locations of the GPS antenna, and (b) components and connections of VRA sprayer prototype.

necessary electrical connections were mounted on the platform. The EZ-Boom system (Trimble Navigation Ltd., Sunnyvale, Cal.) automatically controls the individual boom sections to minimize overspray and untreated gaps that may occur on angled end rows, terraces, waterways, and other no-spray areas within a field. Further, a geographic information system (GIS) could provide field information such as application maps, field prescription maps, detailed application reports, etc. An assisted manual guidance system (EZ-Guide

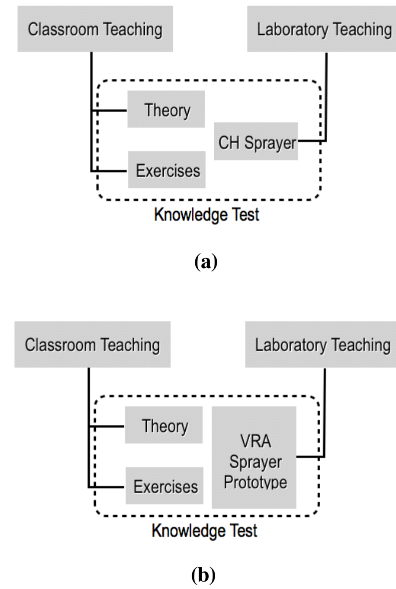

Figure 2. Teaching process for (a) undergraduate students who followed the teaching process with the conventional sprayer and (b) undergraduate students who followed the teaching process with the VRA sprayer prototype.

500, Trimble Navigation Ltd.) with the GPS antenna mounted 1.5 m above ground, capable of sub-meter accuracy, was connected to the sprayer harness to provide position data to the system.

After the sprayer was assembled, the flow sensors and nozzles were calibrated following the manufacturers' recommended procedures. Following calibration, three spraying prescriptions were written using Farm Works (Trimble Navigation Ltd.) mapping software. Finally, the students' (n = 20) satisfaction was assessed. During the course's final exam, the students were asked to answer an anonymous question (question Q1 in table 1) to determine their opinion regarding the suitability of the prototype equipment as a learning tool.

Agricultural Machinery Course and Experimental Design

The VRA sprayer prototype was introduced as a teaching tool in an Agricultural Machinery course during the fall of 2010. This course was divided into two sections: classroom

Table 1. Student questions for the Precision Agriculture and Natural Resource Engineering course and the Agricultural Machinery course after the prototype development activity.

Question	Question	Possible Answers		Percent	No. of Answers
Q1	Do you consider that the development of the VRA sprayer prototype has been helpful for your education in Precision Agriculture and Natural Resource Engineering?	a)	Yes, it provides a practical focus to the course.	35	7
		b)	Yes, but I believe the time and effort spent is is very high and may not compensate.	40	8
		c)	No, it's something that I can learn easily in the future when I leave the university.	10	3
		d)	No, I get the same education with a conventional sprayer attached to a tractor.	15	2
		e)	Don't know/didn't answer	0	0
Q2	Do you think it is interesting to add the use of prototypes as teaching models to improve the teaching quality?	a)	Yes	70.4	50
		b)	No	18.3	13
		c)	Don't know/didn't answer	11.3	8

teaching (theory and exercises) and laboratory teaching (application of agricultural equipment) (fig. 2). The laboratory teaching section displays, describes, and demonstrates agricultural machines.

Currently, the students in the Agricultural Machinery course form four main groups (A, B, C, D). There are also two practice subgroups per main group, making a total of eight subgroups (A1, A2, B1, B2, C1, C2, D1, D2) of between 14 and 17 students each. The total number of Agricultural Machinery students for 2009-2010 was 124. When testing a sprayer (laboratory teaching), each of the subgroups was randomly divided in half. The first half used the VRA prototype sprayer (PS), while the rest of students used a conventional hydraulic sprayer mounted on a tractor (CS). All of the subgroups had received theoretical training on this type of machinery a week earlier. To standardize the students' theoretical training, the three professors of the subject had agreed on the material and visual resources used during the course.

After the laboratory teaching, a short-answer assessment test was conducted consisting of ten multiple-choice questions, each with one possible correct answer (see Appendix). To determine any difference in learning between the prototype and conventional sprayer subgroups, the instructors assigned the following mutually exclusive classifications to the questions: five questions related to theory, two questions related to the conventional sprayer, and three questions related to the VRA sprayer prototype. To avoid carry-over effects, the short-answer assessment test maintained the proportions indicated above but contained different questions for the eight subgroups. In addition, to assess the level of student satisfaction with the prototype a week after the laboratory teaching, a survey question was asked (question Q2 in table 1). The students answered voluntarily and anonymously. The WebCT platform (Blackboard, Inc., Washington, D.C.) was used to administer the questions. This was particularly useful during the optional survey questions.

Statistical Analysis

For data analysis, univariate factorial analysis of variance (ANOVA) and covariance (ANCOVA) were performed. Three fixed factors in a completely randomized design were used. The factors were the teaching method (TM), attended theory (AT), and repeated (R). Each design factor had two levels (yes and no).

The variable "repeated" refers to the students who retook the course. Students who obtain a score of 5 (maximum of 10) or higher cannot repeat the course. Those with a score below 5 must repeat the course since the subject matter was not adequately learned. At the University of Seville, this subject matter is divided into a theoretical and a practical course. The university stated that attendance was voluntary for the theoretical course and mandatory for practical course. Therefore, some students attended both the theoretical and practical course, while others attended only the practical course.

The model-dependent variables were the score on theory questions (ST), the score on VRA sprayer questions (SPS), the score on conventional sprayer questions (SCS), and the overall score on the short-answer assessment test (SSA). Scores on the different variables ranged from 0 to 5 (ST), 0 to 3 (SPS), 0 to 2 (SCS), and 0 to 9 (SSA). The SSA was obtained as:

$$SSA = ST + \frac{2}{3}SPS + SCS \tag{1}$$

When it was not possible to comply with the terms of this type of model, robust ANOVA was carried out to verify the initial results obtained by classical ANOVA. In this case, the null hypothesis of equal 0.1-trimmed means was contrasted. Differences between means in the ANOVA and ANCOVA models were performed using least significant difference test ($\alpha = 0.05$) for the classical models and the Yuen-Welch test (Yuen, 1974) for robust models. The homogeneity of variances was tested using the Levene test, and normality was tested using the Shapiro-Wilk test. Analyses were performed with IBM SPSS Statistics 19 and R software.

Results and Discussion

An automatic VRA sprayer, which used a GPS prescription map to determine its geospatial position and control the spray valves in the field, was successfully developed and operated in a workshop at the University of Seville as part of a Precision Agriculture and Natural Resource Engineering course. The system was specifically designed to optimize the spray application according to information regarding crop type. It was also used to assess a prototype-based method of teaching and learning in an Agricultural Machinery course. The prototype was coordinated with other research projects (Dickinson et al., 2007; Ma et al., 2010).

Once all the components were assembled on the mobile platform, the sprayer was tested in the workshop by simulating situations that might occur in practice. The component systems included mechanics (stability of the boom, hose length, etc.) and electric (cables, voltage levels, power, communication equipment, etc.). Preliminary equipment calibration tests were performed at a constant speed of 0.375 m s^{-1} (1.35 km h^{-1}). These tests demonstrated good performance based on the coefficient of determination (R^2) for pressure (kPa) and application rate (L ha^{-1}) measurements. In all three trials, a value close to 1 was obtained (R^2 = 0.9984, 0.9988, and 0.9992). This shows that the nearly 100% of the dose variation can be explained by pressure. For calibration, the Salyani and Serdynski (1993) methodology was employed.

The educational benefits centered on issues of understanding and operating the equipment, integrating multiple technology systems, developing laboratory tests, collecting and managing agronomic data, and managing real-time field challenges. In these aspects, no quantifiable results were evident. However, the instructors found the process to be a powerful learning experience.

In the Precision Agriculture and Natural Resource Engineering course, response frequencies for the anonymous survey question (question Q1 in table 1) were 35% (a), 40% (b), 10% (c), 15% (d), and 0% (e). In general, students who built the prototype under the guidance of a teacher were satisfied with the experience, as evidenced by the 75% positive answers for Q1. The percentage of satisfied students is in agreement with results obtained by Díaz-Lantada et al. (2007) in a study of teaching applications for rapid prototyping technologies. It is also noteworthy that 40% of the students indicated that building the prototype was time intensive. In the research conducted by Díaz-Lantada et al. (2007), the average score on the student questionnaires reflected that stu-

Table 2. Frequencies of combinations of the factors considered in the study.[a]

Teaching Model (TM)	Attended Theory (AT)	Repeated	Percent of Total	*N*
CS	No	No	3.23	4
		Yes	6.45	8
	Yes	No	21.77	27
		Yes	21.77	27
PS	No	No	4.84	6
		Yes	3.23	4
	Yes	No	17.74	22
		Yes	20.97	26

[a] CS = conventional sprayer, PS = prototype sprayer, and *N* = number of undergraduate students.

dents had to devote excessive time to the project. Activities of this type are not common in courses and may require extra effort because the students are accustomed to receiving a fixed agenda for courses. However, the experience was positive. For students who are comfortable with experimentation and hand work, the construction process can be quite stimulating, whereas those who prefer more theoretical approaches can use the prototype to demonstrate how theoretical principles work in real situations (Torres, 2011), as we did in the simulations of flow and pressure relationships. In addition, only 10% of the students indicated that the development of the prototype was an experience that could easily be learned outside the university. One of the goals of education is to help students make sense of what they learn (Bransford and Schwartz, 1999), and the construction of this prototype is a clear example of this.

With respect to the Agricultural Machinery course, the frequency distribution of the groups formed by combinations of the study factors is shown in table 2. Analysis of the data indicated that the covariate of the number of times a student repeated the course was not significant in any model. The p-values equal 0.485 (ST), 0.994 (SPS), 0.954 (SCS), and 0.569 (SSA) (ANCOVA values are not shown).

The TM factor was not significant in the dependent variable ST (table 3) since the theory questions did not directly relate. Nor was significance detected in the SSA analysis. This is reasonable since 50% of the short-answer test score came from theory (ST). In contrast, the SPS and SCS variables were significantly influenced by TM ($p < 0.001$). Undergraduate students assigned to one or another method of sprayer learning responded better to one or another subset of test questions directly related to their experience. This, together with the fact that the average short-answer assessment scores were very similar (4.99 and 4.97, see table 4), leads us to believe that both methods are complementary rather than substitutes.

Table 4. Average scores in questions about theory, the VRA sprayer prototype, the conventional sprayer, and the final scores.[a]

Factors and Levels[b]		Theory Score (ST)[c]	VRA Prototype Score (SPS)[d]	Conv. Sprayer Score (SCS)[e]	Final Score (SSA)[f]
TM	CS	2.48 a	1.81 a	1.33 a	4.99 a
	VRA	2.76 a	2.59 b	0.53 b	4.97 a
R	Yes	2.77 a	2.38 a	1.09 a	5.46 a
	No	2.43 a	1.97 a	0.81 a	4.51 b
AT	Yes	2.59 a	2.14 a	0.94 a	4.91 a
	No	2.68 a	2.36 a	1.00 a	5.32 a

[a] Values followed by different letters within each column and factor are statistically different at the indicated p-value in table 3.
[b] TM = teaching method, CS = conventional sprayer, VRA = variable-rate application, R = repeated, and AT = attended theory.
[c] Score of 0 to 5.
[d] Score of 0 to 3.
[e] Score of 0 to 2.
[f] Score of 0 to 9.

The scores obtained by students, as shown in table 4, cannot be classified as high in the ST variable. The scores of 2.48 and 2.76 points out of 5 are equivalent to 5.0 and 5.5 points out of 10, which are known in Spain as "sufficient." Similarly, the SSA variable scores of 4.99 and 4.97 points out of 9 with the CS and VRA teaching models, respectively, are also "sufficient." The rating of "sufficient" in questions on theory, with that variable being 50% of the questionnaire, had great influence on the final (SSA) score. Regarding the SPS and SCS variables, the ratings are more acceptable. For SPS, the students scored 1.81 and 2.59 out of 3 points, for a success rate of 60% and 86%, respectively, while for SCS, which is scored on a scale of 0 to 2, the success rates are 66% and 26% depending on the teaching method. According to our experience, these results are not atypical, considering that the test was conducted with students from various courses in the Department of Agriculture. Students generally do not study theory diligently.

In our view, four aspects are involved in all teaching processes, regardless of whether the teaching is effective or ineffective, traditional or innovative: all teachers require knowledge of the course material, make decisions about the course design, interact with students, and manage course activities. This view implies that teachers who desire to improve their teaching abilities can do so by improving their competence in one or more of these four teaching fundamentals. Improving any of these teaching aspects facilitates an increase in the overall scores upon the post-test for the following year.

Table 3. Robust analysis of variance for scores in questions about theory (ST), the VRA sprayer prototype (SPS), the conventional sprayer (SCS), and the final scores (SSA).

Sources of Variation	df	Theory Score (ST) F	Theory Score (ST) p	VRA Prototype Score (SPS) F	VRA Prototype Score (SPS) p	Conventional Sprayer Score (SCS) F	Conventional Sprayer Score (SCS) p	Final Score (SSA) F	Final Score (SSA) p
Teaching method (TM)	1	1.80	0.207	17.64	<0.001	31.30	<0.0001	0.044	0.840
Repeated (R)	1	3.40	0.092	3.82	0.076	1.59	0.234	7.340	0.014
Attended theory (AT)	1	0.03	0.865	0.21	0.655	0.35	0.568	0.634	0.437
TM × R	1	0.67	0.432	0.59	0.459	0.68	0.427	0.279	0.604
TM × AT	1	0.20	0.660	0.26	0.620	0.41	0.535	0.016	0.902
AT × R	1	0.83	0.381	0.03	0.865	0.45	0.515	0.278	0.605
TM × AT × R	1	0.07	0.797	0.05	0.827	3.52	0.087	0.944	0.344

We understand that the students' education, and therefore their test scores, would improve if they received a practical section with both the conventional sprayer (CS) and the prototype sprayer (PS). For learning purposes, given that there was no difference between the final scores of the short-answer assessment test, and given the simplicity of using a conventional sprayer over building a prototype, the CS could be a good alternative in cases where funds are lacking. However, limited funds would not allow the possibility of acquiring the necessary components for incorporating precision agriculture into the tractor-sprayer hydraulic equipment. The total cost of the prototype sprayer was approximately 6,000 Euros, excluding the GPS receiver, which was shared with other research and teaching projects. The equipment cost was much lower than the cost of precision agriculture equipment for a tractor (approximately 10,000 Euros). This cost aspect was a critical concern for the Department of Agricultural Engineering at the University of Seville.

The R factor was significant in the SSA variable. For two of the three remaining variables (ST and SPS), there was a low p-value (see table 3), but it was not sufficient for rejection of the null hypothesis. Although not significant, the scores for variables ST, SCS, and SCS were always higher for students who retook the course (table 4). This was reflected in the significant differences in the SSA variables ($p = 0.014$), with an average of nearly one point more in the test scores of students who had previously attempted the course compared to those who took the course for the first time (5.46 compared to 4.51). This is equivalent to a 21% higher score of compared to that of first-time students. The fact that students who retook the course obtained the best scores was expected; they had already experienced the subject, which should have enabled them to achieve a better understanding of the material.

The theory scores (AT) did not lead to significant results. Both groups exceeded 50% for correct answers for the variable ST, with 2.59 points out of 5 for those who attended the theory class and 2.68 points for those who did not. In addition, scores for the variable SSA were slightly higher among students who did not attend the theory class compared to those who did (5.32 compared to 4.91). This result was not expected by the instructors, since 50% of the assessment test questions were based on theory. The theory lecture took place a week before the assessment, and the scores do not differ substantially whether or not the student attended the theory class. This anomaly requires explanation, and two explanations are suggested. The first possibility is that the instructor explained that a written test was to be conducted on the sprayer within seven days. This enabled all the students to prepare for the test by using the prepared notes, which were freely available at the university. This would invalidate the initial differences between the groups. The second possibility involved instructor observations. Some of the students who attended the theory class did not study diligently. These student's test scores would then be similar to those who did not attend.

The interactions were not significant in any model. A total of 71 students answered the survey question (question Q2 in table 1). The results were 71% (yes), 18% (no), and 11% (don't know/don't answer). Those attending the Agricultural Machinery course showed a good level of satisfaction with the prototype teaching method according to a 71% agreement response, which encourages its probable use in future courses. This experience paves the way for the use of prototyping and new teaching practices as a way to increase interaction between students and teachers and to improve the students' understanding of the Agricultural Machinery course.

Conclusions

A prototype laboratory sprayer (instrumentation, sensors, and actuators to enable variable-rate application treatment) was designed and developed by undergraduate students in a 2009 Precision Agriculture and Natural Resource Engineering course. The following year, the prototype VRA sprayer was evaluated as an innovative teaching tool in an Agricultural Machinery course. The following conclusions were drawn based upon the results of this study:

- The design and development of the prototype was a positive experience for the students in the Precision Agriculture and Natural Resource Engineering course. However, a percentage of the students indicated that the prototype process required time-consuming activities beyond those of the conventional teaching method.
- The VRA sprayer prototype provided a complementary alternative teaching method that improved the students' understanding in the Agricultural Machinery course, according to the test results. Building and operating the prototype illustrated and emphasized applied engineering. In addition, fitting the prototyping activity into their schedules required the students to develop their time-management skills.
- Economic motivation can provide increased interest in the use of prototypes. The total cost of the prototype sprayer was 40% less than the cost of retrofitting a conventional sprayer with precision agriculture equipment.
- Prototype-based teaching focuses on new issues that may not otherwise be covered due to lack of equipment or time. Retaking the course was a factor that led to test score differences among the students.
- Students who took the Agricultural Machinery course believed that the prototype improved the quality of teaching. This indicates that the undergraduate students' learning experience has been enhanced.

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Appendix: Sample Assessment Test

In the following sample assessment test, (T) indicates theory, (CS) indicates conventional sprayer, and (PS) indicates prototype sprayer. The indicators (T), (CS), and (PS) were not shown to the students.

Mark the correct answer

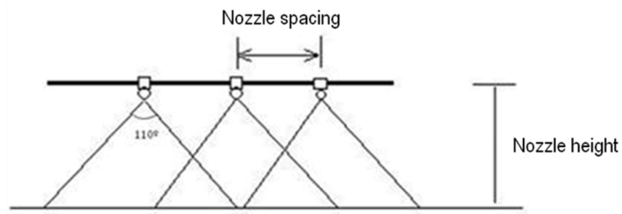

Figure A1.

1. Essential elements of a typical hydraulic sprayer are: (T)
   a) Pump, tank, distribution system, boom, and nozzles.
   b) Fan, tank, distribution, and GPS system.
   c) Chassis, fan, nozzles, and automatic boom section control.
2. Increased pressure in a typical hydraulic sprayer: (T)
   a) Significantly increases the flow and the opening angle of the jet nozzles.
   b) Decreases the flow and increases the droplet size.
   c) Increases the droplet size and decreases the opening angle of the jet nozzles.
3. Recommend the appropriate height of the nozzles, shown in figure A1, knowing that the nozzle spacing is 0.5 m and the patterns of adjoining nozzles must be overlapped by 100%: (T)
   a) 1/tan(55°) cm
   b) 0.5/tan(55°) cm
   c) 0.5/tan(110°) cm
4. Determining factors for drift are: (T)
   a) Droplet size and weather conditions during application.
   b) Weather conditions during application and quality of tractor driving.
   c) Vehicle speed in normal working conditions.
5. A variable-rate prescription map: (PS)
   a) Represents the scheduled application rate for the input variable.
   b) Represents the spatial variability of production.
   c) Represents the physical and chemical properties of the soil.
6. Automatic boom control section is designed primarily: (PS)
   a) To control several individual sections, closing and opening nozzles as necessary.
   b) For an automatic guidance system on a tractor.
   c) To cause an increase in the use of pesticides.
7. Based on figure A2, indicate which configuration is correct: (PS)

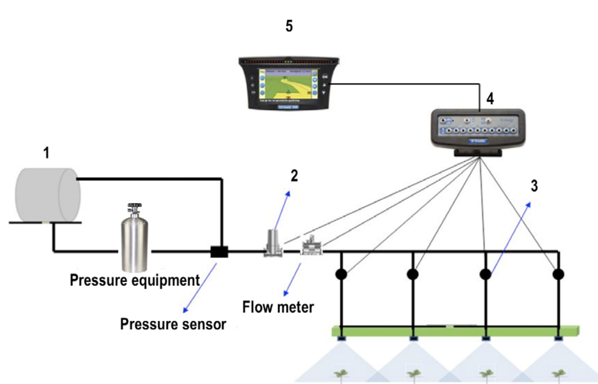

Figure A2.

Figure A3.

a) 1-tank, 2-boom control section, 3-boom valves, 4-GPS, and 5-control valve.
b) 1-tank, 2-control valve, 3-boom valves, 4-boom control section, and 5-GPS.
c) 1-tank, 2-GPS, 3-boom valves, 4-boom control section, and 5-control valve.

8. Is the basic difference between hydraulic and hydropneumatic spray in normal working conditions: (T)
   a) The transport system of the liquid from the nozzle to its target.
   b) Only the pressure supplied to the liquid.
   c) Only the pump equipment.
9. The usual filters on a typical hydraulic sprayer are: (CS)
   a) The tank filter, aspiration filter (before the pump), and individual filters to the nozzles.
   b) The tank filter, pump filter, and individual filters to the nozzles.
   c) The same as in b) but the pump filter is before the pump so that it is not damaged.
10. The roughly spherical component shown in figure A3 is: (CS)
   a) A pressure regulator.
   b) Part of a hydro injector.
   c) A reboiler for thermal shock.

Nomenclature

ANCOVA = analysis of covariance
ANOVA = analysis of variance
AT = attended theory class
CS = conventional sprayer
DGPS = differential global positioning system
PS = prototype sprayer
R = repeated the course
SCS = score on conventional sprayer questions
SPS = score on prototype sprayer questions
SSA = short-answer assessment test
ST = score on theory questions
TM = teaching method
VRA = variable-rate application