A robot from the scratch in 5 months. How agronomy students could master agricultural equipment innovation

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Abstract: *Education and training are identified as key elements to support precision agriculture in Europe and operationalize the transition towards sustainable production systems. In particular, the French agricultural machinery sector is aware that leveraging precision agriculture requires a closer consideration of the farmers' needs. Hence, educational programs are expected to bridge the gap between agriculture and machinery design and innovation. In this paper we will discuss the learning process that led a group of students in agronomy at mastering robotics and how this could help improving educational programs on agricultural equipment. The context was a competition organized by a French applied agricultural research organization that challenged students to build a robot for the mechanical weeding of sugar beet. The teachers adopted a design thinking approach, supporting the students only if needed, rather promoting the students' appropriation of the subject. The farming experience of the students allowed them to choose the simplest sensor, which used the plants as physical boundaries of the robot navigation corridor. This simple and robust solution exploited the agronomic characteristics of the sugar beet that is sown on straight lines and it is not damaged by physical contact. Furthermore, this choice was suited for working in field conditions and easily understandable by the practitioners. In conclusion, we discuss the lessons learned about the environmental and educational conditions that allowed this experience and that could help agricultural students and farmers at mastering new technologies and equipment innovation.*

Keywords: *Student project, farmers' innovation, master degree, agricultural equipment, educational program, new technologies, open source*

Introduction

Education and training are identified by the European Union as key elements to support the transition towards precision agriculture, which is meant to improve the field resource management and promote sustainable farming (Kritikos, 2017). Sustainability and innovation can be understood as synonymous if intended as processes "… of matching the problems (needs) of systems with solutions which are new and relevant to those needs (…)" (Rickards 1985:28 cited in Lehmann et al., 2008). In this regard, precision farming is identified among the 10 technological innovations that could change our lives by making agriculture simultaneously more productive and more sustainable (Kurrer et al., 2017). Though, it was stressed that the deployment of precision agriculture requires a high level training of farmers (Kempenaar and Lokhorst, 2016).

Educational programs are therefore expected to bridge the gap between agriculture and technological innovation. Beyond, a French farmers' manifesto about technologies (InPACT, 2016) has called for a greater involvement of the farmers in the innovation process, to be oriented on their needs and the conditions of use of agricultural equipment. Furthermore, a report promoted by the French Ministry of agriculture identified the innovation of agricultural equipment as one of the levers for the agroecological transition (Machenaud et al., 2014). On their side, the French agricultural machinery manufacturers also recommend strengthening the skills and resources of the sector, in particular to bring training closer to actual field needs (Bournigal, 2014).

Altogether, agriculture is challenged by breakthrough changes that require farmers to expand their knowledge to be able to master recent farming innovations such as digital machine control, embedded sensors, big data management, etc. Thanks to the lowering cost and miniaturization of advanced technologies, farmers are pushed and eager to shift from intuitive to fact-based farming practices: chemical inputs, genetic responses and environmental condition can finally be controlled and accounted for at the intra-field level (Aqeel-ur-Rehman et al., 2014; Bencini et al., 2012). The increased data collection and monitoring capacities are indeed answering the need for a better use of natural resources to reduce farming trade-offs, thus meeting the society expectations for sustainable development. Yet, the fast increasing amount of harvested data remains largely unexploited because the first users, the farmers, are poorly involved in the development of processed information relevant for their decision making.

The improvement of initial learning and the enhancement of life-long learning emerge across studies as one of the most important key for the successful problem solving and innovation processes in agriculture and rural areas. In this context, learning should be considered as part of a complex interaction and communication processes composing the so-called “agricultural knowledge and innovation system”. Accordingly, training programs and support services to improve this system are gaining increasing attention and relevance in education, research and practice. This overwhelming dynamic is being addressed by innovation in training and educational programs, as well as by new forms of knowledge transfer.

Numerous studies have explored so far the acceptability and adoption of precision farming techniques by farmers (Paustian and Theuvsen, 2016; Pignatti et al., 2015; e.g., Reichardt et al., 2009; Toma et al., 2016). Few studies have instead addressed the farmer perspective on new technologies: That is shifting the focus from the relevance and uptake of existing solutions toward a farmer centred innovation design. For instance, Redhead and colleagues (2015) found that farmers were interested in the idea of assembling ‘flat-pack’ robots for early prototype testing. In addition, they stressed that farmers welcome an open source model both for the mechanical build and for the software so as to ensure ongoing maintenance and adaptability as well as to encourage the participation from farmers (Redhead et al., 2015). Openness is changing the way of doing science (Lowndes et al., 2017) and it is boosting the vulgarisation and engagement of citizens (Merilhou-Goudard, 2016). Similarly, open approaches are attracting the attention of farmers to enhance the adaptation of technologies to local field needs and to ease the transmission of knowledge. Examples like Open Source Ecology (http://opensourceecology.org/) and the French homologue Atelier Paysan (https://www.latelierpaysan.org/), or open source farm data hacking (https://www.farmhack.nl/en/) supported by the Global Open Data initiative (GODAN) show the interest for boosting grassroots innovation path drawing upon free access to others' experiences. By the way, openness appears as a possible response to the proliferation of data formats and incompatibility between the multiple single-task software needed to manage the recent equipment or composing the wide panel of decision support tools (Wolfert et al., 2017). Altogether, many data are collected, but only a minor part of that is really exploited, thus slowing and hampering the full deployment of data-based technologies.

In this context of (i) rapid development of precision agriculture, (ii) need for improving the skills of farmers at mastering technological advances, and (iii) opportunities delivered by the open source data and knowledge repositories, a group of students in agronomy was challenged to build a robot from the scratch. Their only background knowledge was in agronomy and agriculture. In this paper we present the learning environment and the lessons learned by the group of students that participated to a robot competition and succeeded the challenge. In conclusion, we will discuss how this experience could improve educational and training programs and help participant at mastering innovation in agricultural equipment. The project has being documented on an open source platform with the goal to feed the agricultural knowledge and information systems of a new agricultural innovation platform.

Learning environment

Lack of knowledge and cost are widely identified as the two main obstacles that farmers have to overcome to involve into new technologies (Doye et al., 2000; Pignatti et al., 2015; Reichardt et al., 2009). To overcome these obstacles, we tested a self-organised learning process as a way to fully mastering innovation. In the current context of a “learning society”, such a learning-by-doing approach is needed, on the one hand, to materialise and thus handle the technological advances. On the other hand, the adoption of a problem-oriented and project-based learning was recognized so far as a relevant way to help students to form a critical mind and to handle uncertainty of increasingly complex systems (Le Méhaute et al., 2007; Lehmann et al., 2008). Altogether, this meets also the call to explore innovative organizational configurations to go beyond the traditional educational lecture-based approaches (Benetos and Peraya, 2013; Ma et al., 2016).

Educational environment and background

A project-based learning requires the teachers to change their role on the same for principles that underpin participatory methodologies in research: group-learning process, acceptance of multiple perspectives, facilitation leading to transformation and learning leading to sustained action (Gibbon, 2012, p. 102). We present here a project-based learning process that involved 5 students in agronomy at UniLaSalle.

UniLaSalle is a centre for higher education in earth, life and environmental sciences organised on three campuses in northern France (Beauvais, Rouen Rennes). The educational cycle is organised on five years. The core curriculum is taught in the first three years of the program. This bachelor period is meant to provide the students with a solid background in agricultural sciences and agronomy, which is expected to be sufficient to run a farm autonomously. The last two years allow the students to choose among different specializations covering the main sectors in agriculture, agronomy and the food industry. Part of the students comes from families already working in the agricultural sectors. Nevertheless, from the first year of the educational cycle, all the students are prompted to experience farming activities with dedicated short training period in farm all over France or even abroad.

In 2016 a new specialization was started in agricultural equipment and new technologies (AENT). The 2-year master provides the students with theoretical background on soil physics, mechanics, computer-assisted design, and machinery solutions for main farming practices. The teaching is delivered either by UniLaSalle professors or by experts in the sector coming from the industry and the agricultural sector. In addition, the students are required to develop some applied projects.

The first graduation was composed by five students, all sons of farmers and with a solid background in farming. As mentioned, in addition to the theoretical courses, the students developed some applied projects. During the first semester, they were involved in two activities. First, they contributed to define the specifications of an innovative tractor with students from an engineering school in mechanics. This first project allowed them to experience the interdisciplinary dialogue and, namely, to have a first contact with a sector-specific expertise. At the same time, the AENT students were asked to produce a database of the agricultural robots available in France. The database led the students to define what a robot is, then to collect and organize technical information about robots already on the market or existing as prototypes. The database includes 100 robots with full specifications retrieved from technical magazines, producer websites and similar sources (Rizzo et al., 2018). For comparison, on the same period the “Agricultural Robots” report focused on 149 profiles (Tobe, 2016). Of note, the students were asked to stress the vehicle-soil interface. Altogether, the design and development of the database provided the student with an implicit catalogue of several existing robotic solutions in agriculture.

The robot competition occurred in the second semester. Even against the previous projects and courses, the students considered themselves as complete outsiders for the robot competition because they received no specific training on robotics, electronics and similar disciplines. So, they decided to follow strictly the competition guidelines. The pedagogic goal was to allow them to overcome possible knowledge barriers with a learning-by-doing approach and to facilitate experience exchange and capitalisation.

The competition

The context was a competition named “Rob’Olympiades” and organized by a French applied agricultural research organization (Arvalis, Institut du vegetal) that challenged student teams to build an agricultural robot. Although at its first edition, the competition guidelines were quite clear and constraining, so facilitating the design process of the students who can simply focus on the expected task: weeding a field of sugar beet. Indeed, new competitions can pursue innovation in a broad sense, thus providing only general guidelines, though leaving too much options to explore to newbies (Oksanen et al., 2009).

The guidelines were diffused late November 2016 and declared as educational goal, prompting the students team to create a functioning robot and fostering the cooperation outside the academia. Three challenges were defined for the competition: tillage, weeding and freestyle, with a strong incitation to create from the scratch the maximum number of features. Being a competition for an agricultural robot, the guidelines clearly specified also the field crop characteristics and the penalties for the crop damages. In addition, the robot was required to be completely autonomous and no navigation remote control was allowed (Chavassieux, 2016).

Leading education towards innovation mastering

The students were initially resistant to involve in the high challenging competition. So the support teachers created the opportunities for learning and overcoming the knowledge barrier through negotiation (Oksanen et al., 2009). The teachers adopted a design thinking approach, supporting the students only if needed, rather promoting the students’ appropriation of the subject. The modernization of the educational process was therefore pursued by creating room for the students creativity applied to a real problem, namely by seizing the opportunity of the official competition addressing a real-world problem (Bazylev et al., 2014). On the one hand, a functioning prototype was the goal to participate to the competition. On the other hand, the teachers evaluated the students on the production of the related instruction materials, part of which was meant to feed the open source documentation available at http://agrilab.unilasalle.fr/projets/projects/rob-olympiades-2017-unilasalle/wiki Of note, the students were “only” required to complete a robot that can move on the start line of the competition, leaving the fulfilment of the competition itself as a free bonus.

The students team divided the global goal into smaller tasks, then distributed among the team members. The various buying orders for the robot components provided on-the-go checkpoints and milestones to ensure the respect of the timetable. Overall, the team was supported rather than directly guided. The teachers and experts’ role was clearly limited to answer the questions coming from the students to help them find the solutions. At a point that even when clear mistakes were emerging, no correction was adopted by the support team so as to leave the students learn the lesson. For instance, the electrical engine power was underestimated. Nevertheless, the order was completed and the engines burnt as expected. All in all, the correct engine dimensioning is a crucial factor of success for a well-operating robot, and the students were then fully and *practically* aware of this aspect, far beyond of its *theoretical* comprehension.

In line with the learning-by-doing approach, the students applied their theoretical knowledge of 3D computer assisted design to translate into reproducible blueprints what they had imagined and prototyped with wood and other raw materials. The students’ agricultural and agronomic background allowed so to correct a common research and development approach that considers farmers as simply end-users. In fact, working on the acceptability of top-down innovations in agriculture eventually fails at embracing the complexity of farmers' decision making (Douthwaite and Hoffecker, 2017). We pursued instead the full mastering of innovation by the students who happened to have also a young farmer profile.

Project management

The five students at the first year of the AENT specialization were required to completely manage the project, though with the possible assistance for the practical aspects by a support team composed by the AgriLab® manager, the associate professor in mechanics and other experts. AgriLab® is the collaborative innovation platform for agriculture innovation based in Beauvais (northern France) that hosted the project deployment.

All along the project the students team was asked to produce the documentation enabling to reproduce their prototype and to keep track of their trials and errors. The public accessible documentation is structured on five steps.

First the team building. As said before, this was a project for the AENT specialization master. The first semester project already allowed them to know how to work together. The second step was the brainstorming about the concept robot and its components: frame, weeding tool, locomotion, and engine. More in general, they opted for mechanical weeding. Given their background and history, it happened that the students mastered welding. They thus opted for a weeding tool that recreated somehow a common weeding farming tool, namely a tine cultivator. The third step was, accordingly, the field tests to measure the strength needed for the effective traction of the selected tool. Hence, the design of the concept robot included field tests in real conditions from the very beginning (Fig. 1).

Figure 1. Dynamometer field test. Source: http://agrilab.unilasalle.fr/projets/attachments/351/RobOlympiades_banc_essai.jpg

Once that the fundamentals were clear, the fourth step was listing the needed components to assembly a prototype of the concept robot, to finally move to its construction. For the last step, the sequence was designing and building: the base frame, the body frame, the tool hitch, the individual hoe tooth and coupling system, the soil-vehicle interface, the electrical scheme and the coding. Of note, early tests with underinflated wheels (Fig. 2) led to selected instead for rubber tracks as definitive option of vehicle-soil interface. A last section of the robot public documentation describes the real field test conditions and the various ongoing issues.

Figure 2. The test field of sugar beet. Source: http://agrilab.unilasalle.fr/projets/attachments/368/RobOlympiades_parcelle_d_essai_ET12.jpg

The characterizing feature of the robot was the autonomous steering system: a flex sensor mounted on a rubber strip. This simple and robust solution exploited the agronomic characteristics of the sugar beet that is sown on straight lines and it is not damaged by physical contact. The farming experience of the students allowed them to choose the simplest sensor, which used the plants as physical boundaries of the robot navigation corridor. Furthermore, this choice was suited for working in field conditions and easily understandable by the practitioners.

Lesson learned

In the words of the students (translated from French):

> *"The idea was to design something simple, and effective, where there is not too much ultra-advanced technology... and, to be in the mood of time, which requires us to use less and less pesticides and herbicides, such as the glyphosate. And then, to prioritize a small machinery, more affordable in terms of use and access, which could be a new way of equipping the farms."*

This excerpt ended a students' interview podcasted on the national French radio titled "Agriculture: towards an ethical robotics?" (Leblond and Voldoire, 2017). A wide media attention was drawn by the fact that the concept robot won the competition out of the three participating teams. Not only the concept robot succeeded at moving autonomously without damaging the crop, but it also performed correctly the expected task: the mechanical weeding of two rows of sugar beet (Fig. 3). In addition the student team tackled also the freestyle challenge, for which they chosen to have the robot following a farmer that manually removes the bolted plants in the row, moving and stopping along with him/her. In this challenge, the student team resumed their experience: the farmer finally master the robot that is meant to support his/her farming practices.

In a wider perspective we can summarize the lessons learned according to the three approaches identified for a problem-based learning: (1) cognitive approach, implying that learning is organised around problems and will be carried out in projects; (2), contents approach, requiring that learning is oriented as exemplary practice to seize interdisciplinarity; (3) collaborative approach, where a participant-directed process contributes to a social act of collective ownership of the learning process (Lehmann et al., 2008).

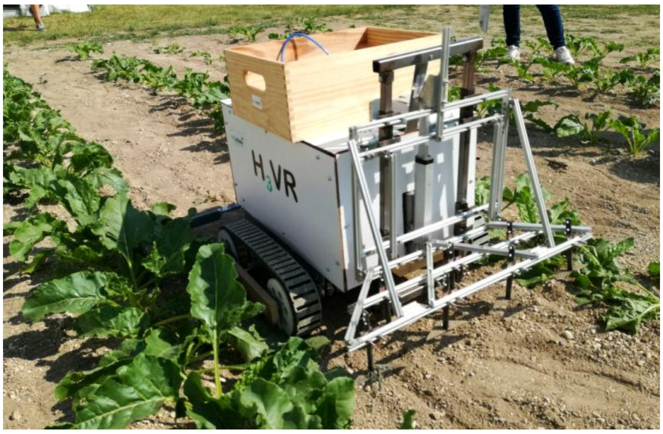

Figure 3. View of the rear side of robot during the competition. Author : Mehdi Jaber (2017)

First lesson: problem-based learning allowed to master technology innovation

The main lesson learned is that a learning-by-doing approach eased the mastering of technical advances even with no apparent preliminary specific knowledge. In particular, the students overcame the knowledge barrier by going through all the process from the design, to the building and testing an operating concept robot (Verner and Ahlgren, 2007). Furthermore, having an imposed (external) deadline induced the students to accomplish the project. This eventually raised their confidence in their capabilities to acquire new skills and to realize innovative solutions. In summary, the full students' engagement was proved by the name given to the robot (H3VR), composed by the first letter of the five team member surnames.

The competition was hard because it asked the participants to design and realize a robot from the scratch. This was way harder of another known French agricultural robot competition called "Move your robot" (MYR) promoted by Naïo Technologies, which is one of the most important French agricultural automation companies (Finistere, 2017). In the technical notice for the 2017 MYR competition, they recall the need to take into account that wheels can slide or be blocked by mud, or rocks, as well as that the ground is not perfect solid glass, so it needs to be calibrated by software (min/max values). One can read also that "farmers are not robots themselves and lines of vegetables are not necessarily straight and can have holes" (Andreu, 2017). In comparison, the Rob'Olympiades faced the student teams with a real-world problem: operationalizing the reduction of pesticides in the sugar beet cropping. And the competition took place in a real field, with real plants. This implied all the difficulties for the robots to move on a rough and irregular ground, in light and dust conditions that could potentially impair sophisticated, yet delicate position sensors. In this regard, the flex sensor mounted on the rubber strips used as position sensor was highly appreciated by the judging commission. One of the competition judges declared (translated from French):

> *"The technology used is simple and robust. The students were able to stay closer to the job of farmer and adapt this job to a robot. This gives quite interesting results"*

Second lesson: the exemplary practice enabled the interdisciplinary learning

The second lesson learned is that by sticking to their background, the students in agricultural engineering succeeded at innovating a field of which they still declare to know nothing: the agricultural robotics. However, the documentation publicly accessible is clearly presented as a concept design and not manufacturing tutorial. That is, it aims to present a concept robot whose features still need further development. Some obvious modifications are highlighted to enable the robot to operate efficiently and effectively. First, the current electronic architecture does not allow speed control, which is essential for the repeatability of actions, so it is necessary to provide specific controllers for the encoders. The flex sensors can be used as is, but their electrical resistance varies over time thus hampering replicability, so a new design based on potentiometers should be preferred. Concerning the vehicle-soil interface, the rubber tracks, currently made of cable protection elements, is clearly unfitted to support traction and easily fouled by soil further reducing its performances and resistance. It would be better to come back to the initial idea of underinflated wheels. Finally, the frame in aluminum is to light to ensure an effective weeding work and should be replaced by a heavier steel frame.

Third lesson: the participant-directed learning is part of a social approach

The third lesson learned is that building on shared knowledge accelerates the innovation and its mastering even by newbies. The five student team demonstrated that a good background in agronomy and the access to shared knowledge can be sufficient to select and use the most appropriate technological solution to design and build an operating agricultural robot. Indeed, the fully operating concept robot was accomplished in only 5 months, whereas the development of a similar commercial agricultural robot taken almost 5 years (personal communication). The Rob'Olympiades competition is open again for the 2018 and a new team of students is planning to participate by improving the first experimental prototype of H3VR. We will observe how the produced documentation will ease the new student team to master the early prototype and develop it further. For this kind of reasons UniLaSalle and other territorial partners decided to create an open source living lab completely dedicated to farmers and all the stakeholders of the agro-food sector. Accordingly, the platform is named AgriLab® and the first project that it hosted was the students' robot. The perspective is to starting a free and open agricultural knowledge information system aiming at facilitating the emergence of farmers' innovations.

Conclusions

Technological innovations continue to revolutionize agricultural practices. Though, the recent fast paced opportunities opened for precision agriculture require farmers to strengthen and rapidly upgrade their skills. We believe that one of the keys to the success of such a revolution is to ease the mastery of innovation through dedicated educational and training programs. In this paper, we presented how this challenge could be faced through a problem-based and project-oriented approach. This approach has no special limitation in terms of integration in the curricular structure, and it is currently applied in different orientations and stages of the studies at UniLaSalle as well as in other higher education institutions. The novelty hereby is in the focus on its potential to improve the education and training in precision agriculture. The self-organised learning process that we presented is being replicated by the following graduation years in agricultural equipment, as well as by involving farmers, other engineering schools and experts in agricultural machineries and digitalization technologies.

In conclusion, we can point out some relevant features of the whole teach-and-learn arrangement. For instance, it will be important to ensure the involvement of students and learners having a direct farming experience (i.e., practitioners), so as to keep the need assessment and problem formulation connected to real life (cf. Nõmm, 2009). The main incentive was to formalize the right for trials and errors. This was crucial to encourage the (future) engineers to face uncertainty, so as to explore beyond their available knowledge by dealing with vague and ill-defined problems (Hatchuel and Weil, 2009). Eventually, the role of teachers was to stimulate the skills to master the opportunities provided by the "neural network" of the current "learning society", where multiple knowledge and expertise are crossed (Le Méhaute et al., 2007). Furthermore, it was important to provide a dedicated space and time arrangement. On the one hand, breaking the routine is known to boost innovation through creativity. On the other hand, it is crucial to question the role of permanent spatial settings for innovation (Bathelt et al., 2017), especially for land based activities like agriculture. In this sense, it was relevant to frame the students project within the creation of the agricultural innovation platform (AgriLab®) so as to wire it to a more structural and long-term collaboration with regional stakeholders (Schut et al., 2016).

In perspective, the engagement of students and farmers through a problem-oriented and project-based learning can elicit the emergence of new business models. The (future) agricultural engineers will join the sparkling landscape of start-ups related to the agricultural activities with enhanced skills to face the project management under knowledge uncertainty. In addition, being (formed as) practitioners, they will contribute with solution better suited for famers, so easing the mastery of technologies that are currently and for the most exogenous to the agricultural sector.

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Author contribution

D.R. and M.J. conceptualized the study and framed the analysis of the results. M.J. curated the wiki documentation with the students. M.J. and A.Y. tutored the students' project, with technical and pedagogical support from B.D. and A.C. Finally, D.R. wrote, revised and edited the manuscript.

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Source Availability Statement: the public documentation of the H3VR robot is available on the AgriLab® collaborative platform and might be accessed from: http://agrilab.unilasalle.fr/projets/projects/rob-olympiades-2017-unilasalle

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