Remote Plant Sensing and Phenotyping – An E-Learning Tool in Higher Education

Hans Bethge [1], Thomas Mählmann[2], Traud Winkelmann[3] and Thomas Rath[4]

Abstract: Within the consortium "Experimentation Field Agro-Nordwest", a practical concept for knowledge and technology transfer of digital competence in agriculture was created. For this purpose, the web-based e-learning system "SensX" was set up, consisting of videos, presentations and instructions. In addition, the classical e-learning concept was extended by data sets, student experiments and sensor data of plants acquired by a remote phenotyping robot. This resulted in a massive open online course (MOOC), which was tested with agricultural and biotechnology students in higher education at the University of Applied Sciences Osnabrück over two years. The evaluation process of "SensX" included an empirical survey, qualitative interviews of the participating students by an external institution and an evaluation of the concept by the lecturers.

Keywords: agriculture; digital competence; e-learning concepts; remote experiments; sensors in teaching

1 Introduction

In higher education, the number of teaching modules based on e-learning systems, blended learning systems (traditional teaching combined with e-learning) or MOOCs (massive open online courses) is steadily increasing both, nationally (Germany) and internationally [Lü20], [Al18]. The majority of these (approx. 30%) are offered in the computer sciences, but almost 6% are part of the agricultural and life sciences curricula, worldwide [Al18]. The COVID19 pandemic has caused further acceleration in the use of e-learning, blended learning approaches or MOOCs in higher education [Be21]. Yet the terms used to describe the use of computer technologies in education (here e-learning, blended learning, MOOCs) vary widely and are not coherent. In many publications and reports, the methods are

[1]University of Applied Sciences Osnabrueck, Laboratory for Biosystems Engineering (BLab), Oldenburger Landstr. 24, D-49090 Osnabrueck, h.bethge@hs-osnabrueck.de, https://orcid.org/0000-0002-3487-9725

[2]University of Applied Sciences Osnabrueck, Laboratory for Biosystems Engineering (BLab), Oldenburger Landstr. 24, D-49090 Osnabrueck, thomas.maehlmann@hs-osnabrueck.de

[3]Leibniz Universität Hannover, Institute of Horticultural Production Systems, Woody Plant and Propagation Physiology Section, Herrenhaeuser Str. 2, D-30419 Hannover, traud.winkelmann@zier.uni-hannover.de, https://orcid.org/0000-0002-2509-1418

[4]University of Applied Sciences Osnabrueck, Laboratory for Biosystems Engineering (BLab), Oldenburger Landstr. 24, D-49090 Osnabrueck, t.rath@hs-osnabrueck.de, https://orcid.org/0000-0001-7277-7335

grouped under terms such as "digital education" or "e-learning". Defined competences should be specified and consolidated. In contrast to the original intention of the Bologna process to focus academic education very strongly on vocational training, digital education in particular is based on four (or even more) areas of competence acquisition: (i) self-competence: ability to act on one's own responsibility, (ii) subject-matter competence: the ability to be able to make judgments and take action in specific areas, (iii) time competence: the ability to plan and carry out actions and intellectual achievements in a chronological sequence, (iv) social competence: ability to make judgements and act in a complex society [Ar18]. When evaluating digital education with regard to the criteria and competences listed above, digital education is sometimes seen as having a disruptive character [Ki19], since universal access makes it possible to support any university. Thus knowledge and methods are, at least in theory, available to many institutions and locations. On the other hand, difficulties are also seen that ultimately cause high dropout rates, e.g. with MOOCs [Ki19]. Empirical studies do not show a uniform picture of the educational success of digital higher education. In an analytical-theoretical study, it was demonstrated that there is only a slight correlation between digital and classic teaching methods in higher education with regard to learning success [Sc20]. In contrast, specific digital evidence-based and tested teaching concepts in the agricultural sector showed the superiority of digital teaching concepts to classical teaching in terms of learning success [We22], [Ke16].

Of course, it should also be noted that the use and success is largely dependent on the users, i.e. the learners themselves. Thus, Kahan et al. differentiated users of MOOCs into five categories: (i) tasters, (ii) downloaders, (iii) disengagers, (iv) offline engagers and (v) online engagers [Ka17]. Each of these groups handles digital education differently and presumably, this leads to strong dispersion in learning success or in other evaluation parameters of digital teaching. On closer inspection, the teaching concepts and methods used in digital education or e-learning are also complex, and the terms used for them are multifaceted, not clearly demarcated, and only partially defined (see the comprehensive table of terms in [Lü20]). [Ca20] distinguished only three teaching approaches: (i) e-learning by distributing, (ii) e-learning by interacting and (iii) e-learning by collaboration. They were able to show that e-learning in higher education is still largely dominated by e-learning by distribution (uploading texts, graphics, PDFs, etc.), while more far-reaching approaches such as e-learning by interacting or e-learning by collaboration often remain largely unexplored [Ca20]. Approaches that go beyond this, such as e-learning supported by self-performing experiments, do not appear at all in the considerations and therefore, seem to be so far unconsidered in digital education and literature. The need to develop educational concepts that go beyond the three approaches of [Ca20] in order to provide efficient and successful academic training in as many areas of competence as possible is becoming increasingly evident.

In agriculture, the field of sensor technologies is very suitable for this purpose, as it is a subject with constantly evolving contents. Additionally, it is gaining increasing importance in all areas of agribusiness, and already plays a dominant role in practice, research, and development (see [Ha19] and [Yi21]). Moreover, students of agricultural sciences usually have little affinity for sensor technologies prior to their studies. So for many of them, a deeper engagement in sensor topics with new e-learning methods can lead to new knowledge, skills and competences. Therefore, the aim of our project is to establish and explore the use of sensor technology in agriculture using an interactive e-learning approach in order to provide students with in-depth digital competence.

2 SensX

2.1 Concept and categories

Within the consortium, "Experimentation Field Agro-Nordwest" a proof-of-concept project called "SensX" was initiated to promote and establish the use of sensor technology in the plant sector at university and college level. For that purpose, a MOOC e-learning system was developed that extends classical e-learning concepts by using sensor data, sensor kits, and, as a future perspective, fully remote and collaborative teaching with a robotic sensor demonstrator (Fig. 1). We have structured the features of the e-learning system into four categories, as described in detail in the following subchapters.

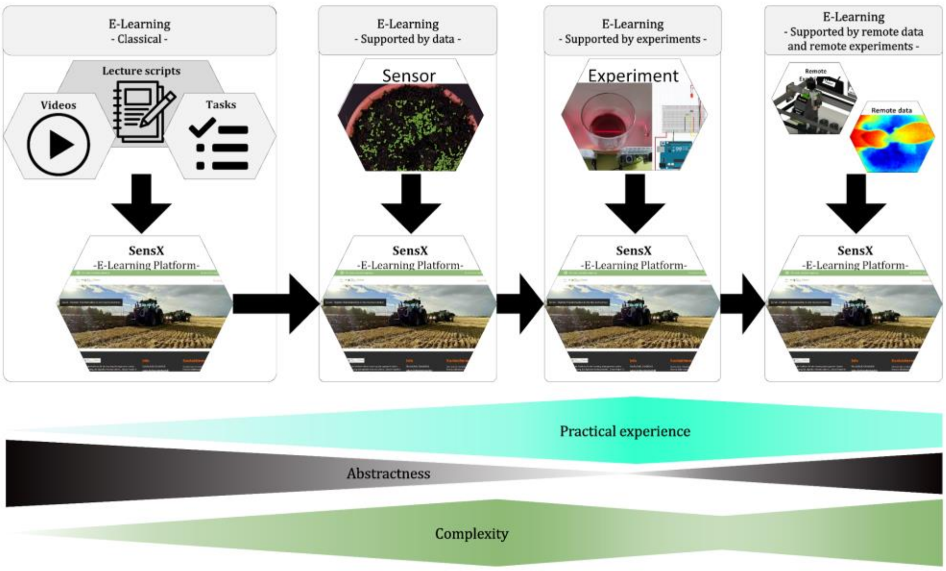

Fig. 1: Supported e-learning concepts of the MOOC platform "SensX"

Classical E-Learning

Up to now SensX contains 12 sessions (see Tab. 1 at the end of this chapter), four of which were structured according to basic/classical e-learning concepts following e-learning by distribution. The transfer of knowledge took place through the exchange of information by uploading lecture scripts, explanatory videos and exercises about agricultural engineering topics, for instance operating principles of specific sensors used in crop production and research, such as ultrasonic and spectral sensors, RGB, NIR and IR cameras, fluorescence spectroscopy, LIDAR (light detection and ranging), soil moisture, temperature and humidity sensors.

E-Learning supported by sensor data

Two of the 12 SensX sessions (see Tab. 1) were conceptualized according to e-learning supported by RGB sensor data sets to demonstrate the measurement of spatially resolved data and their processing with current approaches of artificial intelligence. Based on this, image-processing algorithms were developed to evaluate the generated feature vectors with a neural network.

E-Learning supported by sensor experiments

Since SensX is a hands-on online course, each participant received a sensor kit (worth about 30 €) for the session categorized as e-learning supported by experiments at the beginning of the module. The kit consisted of a microcontroller platform, electronic components and various sensors. This enabled the participants to carry out their own experiments at home and to collect data of plants and other real objects. In addition, for specific tasks, participants carried out exercises with smartphone-based sensors.

E-Learning supported by remote sensor data and remote sensor experiments

In order to also enable multisensory applications at a high academic level, the novel low-cost demonstrator “Phenomenon” was developed [Be22], by which different sensory information from real plants were obtained (Fig. 2). It consists of exclusively low-cost hardware and open-source software components, which were selected to construct a xyz-scanning system with an adequate accuracy for consistent data acquisition and total costs of around 3000 €. The developed device allowing remote control via HTTP of all the functions such as motion control, data acquisition and access of sensor data due to its unique software design. We have installed four different sensors inside the robot, (RGB and thermal camera as imaging sensors, laser-based depth sensor and spectrometer as point measuring sensor) that correspond to the current sensor technologies used in modern agriculture. The resulting data sets provide students with multisensory data acquired remotely from real phenotypic experiments that they learned to handle and process. We already included the resulting data sets of the system in two modules of SensX.

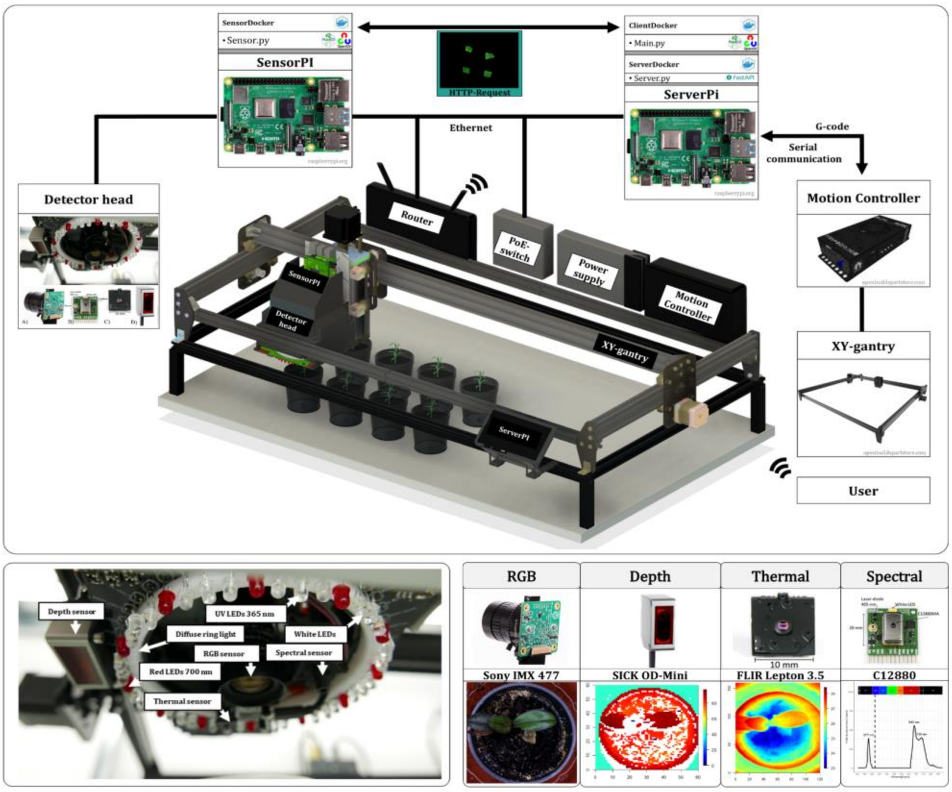

Fig. 2: Demonstrator “Phenomenon” for multisensor technology

Agritechnical content	Category	Hardware
Analog sensor data acquisitions	Basic/Classical	PC
Thermodynamics in greenhouses	Basic/Classical	PC
CO_2-tracer gas method	Basic/Classical	PC
Computer vision (CV) and machine-learning	Basic + data sets	PC + RGB data
Plant classification, CV and neural networks	Basic + data sets	PC + RGB data
Optoacoustic signals	Basic + experiments	PC + Microcontroller
Radiometry & spectroscopy	Basic + experiments	PC + Smartphone
Temperature and spectral data acquisition, analysis and visualization with R/Rstudio	Basic + (rem.) exp. + (remote) data sets	PC + Demonstrator + MCont. + sensor data

Tab. 1a: Sessions and categories in SensX for ***Sensor control and analysis***

Agritechnical content	Category	Hardware
Randomization of experiments in controlled environment	Basic/Classical	PC
Moisture sensor data acquisition	Basic + experiments	PC + Microcontroller
Determination of crop performance traits	Basic + experiments	PC + Smartphone
Spectroscopic Methods and data visualization	Basic + (remote) experiments + (remote) data sets	PC + Demonstrator and Microcontroller sensor data

Tab. 1b: Sessions and categories in SensX for ***Applied technology in crop experimentation***

2.2 Evaluation methods and statistics

The 12 application sessions of SensX were evaluated internally with surveys within two university lectures ("Sensor control and analysis" with 18 participants and "Applied technology in crop experimentation" with 16 participants) addressing agriculture and biotechnology students over two semesters (winter 20/21 and summer 21) at the University of Applied Sciences Osnabrück. Within the surveys the students have to rank a) the different sessions in general (scale: very good, good, average, bad, very bad) and b) the difficulty level of the sessions (scale: very easy, easy, average, heavy, extreme heavy). Because of different semesters, different survey years, different studies and different preknowledge of the students the results were not statistically condensed. Additionally the students were asked to rank every session, which was integrated into their course, with a German grading scale from 1 (like excellent) to 6 (like very poor). These rankings were combined with categories (see above) and statistically analysed with Kruskal-Wallis rank sum test with Fisher's Least Significant Difference using R.

In the following year (summer semester 22, "Sensor control and analysis" with 9 participants) the courses were evaluated externally as qualitative interview by the Institute for Futures Studies and Technology Assessment IZT, Berlin.

3 SensX evaluation

3.1 Internal empirical survey

The internal empirical survey with the participating students revealed that over 90% rated SensX as very good, good or average. However, only 65-70% of the students were satisfied with the clarity and design of the Moodle-based web interface of SensX (data not shown). Participants were highly satisfied with subject-specific content of SensX in general, regardless of the teaching concept (Fig. 3) and there was no significant difference in the overall rating of SensX in terms of the defined teaching concepts (Tab. 2).

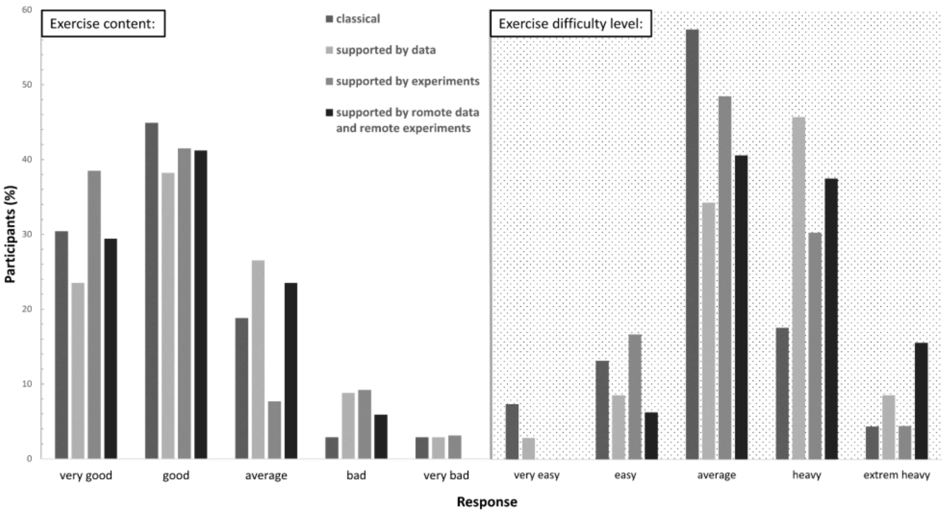

Fig. 3: Internal evaluation of SensX by participants

Concepts	Mean±sd	Median	Count	Rank
Classical	2.13±0.95a	2	70	94.6
Supported by data	2.34±1.19a	2	35	103.1
Supported by experiments	2.27±1.13a	2	66	99.4
Sup. by rem. data and rem. experiments	2.68±1.25a	2	31	119.6

(German grading scale, Kruskal-Wallis rank sum test with Fisher’s Least Significant Difference, α = 0.05)

Tab. 2: Statistical summary of participants' overall rating of SensX by in the internal evaluation

Further analyses by the students regarding the developed sessions showed that there were no difficulties with regard to the usability and the clarity of the presentation of the individual subject contents. This was of great importance, as it was the basic prerequisite for quantitatively evaluating the students' further statements regarding the sessions. In terms of difficulty level, the optimum was exceeded for some participants, in particular when complexity and abstractness (Fig. 1) were increased due to the teaching method. Nevertheless, that also indicated the need for specific teaching tools addressing those skills. This was particularly evident in the sessions with remote data of the “Phenomenon” robot, where 70% of the participants rated the content of the sessions as very good to good (Fig. 3), but at the same time 70% of the participants rated the difficulty level as heavy to very heavy.

The motivation of the students to engage with the sessions of SensX as well as the results achieved in the exams were rated as very good by the lecturers. These evaluations showed that especially the e-learning sessions, which were based on the analysis of data and simple experiments, received very good ratings from the students. The more complex the applications became, the more critically the students rated the individual sessions (see Table 2). These evaluations are understandable, as individual modules with a high degree of complexity demanded a lot from the students, especially methodological and procedural expertise and competence orientation.

3.2 External qualitative interview by IZT

The post hoc analysis of the interviews, conducted and reported by the IZT, revealed that participants rated SensX an average of 7.9 in terms of overall satisfaction on a scale from 1 (low satisfaction) to 10 (high satisfaction). It should be noted that this survey was conducted a year later with other participants of the module and slightly optimized contents of the sessions. The students surveyed the gain in their own digital competence particularly positive being achieved through the independently performed experiments with microcontrollers and sessions regarding computer vision. However, the surveys also indicated that there is a strong desire for more collaboration.

Representative statement from students:

- "I would definitely also say that I was able to take away a lot of digital skills in this module and that will continue."
- "What disappointed me a little bit: I thought we would be standing together more in the greenhouse looking at plants"

3.3 Evaluation by lecturers

In the first six columns, Figure 4 shows the main characteristics and criteria of the developed sessions in relation to the four e-learning categories (lines) that were considered and implemented in the module design.

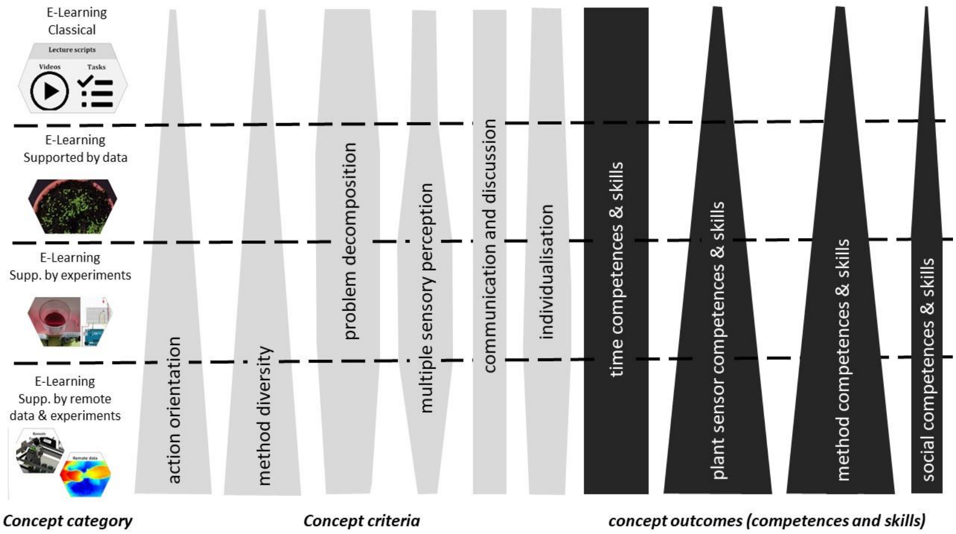

Fig. 4: Criteria of SensX sessions based on experiences of module creators and lecturers and the competence output profile within two years (four semesters) of application

It should be emphasized that the information on the module properties in Figure 4 refers exclusively to the sessions created and the concepts behind them. Nevertheless, Figure 4, columns 1 to 6 provide important information about the general concept of SensX. In contrast, the last four columns represent the actual competences achieved within the sessions based on the evaluations (see chapters 3.1 & 3.2), but also based on the oral and written examination results and the statements made by the students. Summarizing the different evaluations indicated that the new e-learning concept supported by experiments and data analysis mainly raised plant sensor expertise and methodological competence and skills of the participants.

3.4 General discussion

The SensX system presented in this study goes beyond the **classical e-learning concepts** [see Ca20] and uses technical tools that meet today's digital potential and requirements for higher education. Our teaching concept successfully demonstrated the proof-of-concept that an extension of classical e-learning systems by action-oriented methods in the field of agricultural engineering is possible and reasonable.

However, the extension of e-learning requires considerable additional technical and financial effort for higher education institutions. The hardware used (microcontrollers, sensors) must be provided as a kit to each student for home work and should be in the low-cost range so that students can **experiment** with it freely and without prior knowledge. The additional more complex systems required, such as the "Phenomenon" robot in our case, which enables remote experiments at the educational institution, must also meet low-cost conditions. Our "Phenomenon" system fulfils this criterion, costing less than 3000 € [Be22]. It should be noted, however, that remote access to "Phenomenon" requires an open IT structure of the educational institution that is freely accessible from outside. Usually this is not the case, or only to a limited extent. Also in our case, we had to provide students with the data collected on site without direct students' access to the sensor system. Although this limitation can be reduced by video presentations (in our case) or similar documentation, a free **remote access** from outside is actually necessary, or at least desirable, for the complete implementation of our teaching concept. We were therefore, only able to show the perspective of our remote experimental concept, where students will be taught how to remotely program, control and use a remote robot to phenotype a small biological experiment through a collaborative online programming workshop. We are convinced that this will address the identified students' demand for collaborative work.

At this point, we would like to once again highlight the different e-learning types of students [Ka17]. Possibly, here lies a problem of the created system: Due to the high technology employment, for individual students, e.g. the group designated as downloaders, the study within a technical unknown field (developing circuits, calling sensor data with programmed scripts etc.) may need too much time and self-initiative so that no new knowledge or new method competences can be gained. On the other hand, the complex sessions forced students to interact with each other, which is otherwise considered difficult and critical in e-learning systems [Ca20]. Despite the very high content-related, methodical and self-organizational requirements, the students rated our new e-learning concept as efficient and useful in the overall evaluation. Understandably, sessions with their own (easy) experiments tended to score best. Analysis of **complex remote data sets** was rated as very difficult and was obviously at the learning limit of the students involved. Nevertheless, these sessions were generally not devalued significantly, supporting that an appropriate methodological teaching approach was chosen. A direct comparison of the final grades of SensX participants with the final grades of students from the previous five years, which had the same content but no e-learning components, showed a better final grade on average (data not shown). In the evaluations of our overall concept, it is essential to take into account that the newly designed teaching units have so far only been used in the period affected by the COVID19 pandemic, where the boundary conditions were difficult due to the temporary closure of the university and were uncharted territory for all involved. The clarification of possible correlations is still pending and can only be answered after several runs of SensX in different study programs and at different educational institutions.

4 Conclusions

In this article, we have demonstrated the feasibility of a new e-learning approach that addresses the need of modern agriculture for high digital competences in higher education. We propose that a deep understanding of sensor technologies and methods of digital data processing can only be obtained when higher education, which has been dominated by e-learning concepts in the last 2 years due to pandemic circumstances, includes hands-on sessions and is supported by self-performing experiments. Further expansion of SensX will accommodate even more collaborative opportunities for participants and forces to prepare tomorrow's plant sciences students for the challenges of digitized modern agriculture.

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