Outcome-Based Use of Simulation in Agricultural Sciences: A Systematic Literature Review

Anjorin Ezekiel Adeyemi, Shuai Ma, Zhihong Xu, and Rafael Landaverde

Department of Agricultural Leadership, Education and Communications, Texas A&M University

Author Note

Correspondence regarding this article should be addressed to Zhihong Xu, Department of Agricultural Leadership, Education and Communications, Texas A&M University, College Station, USA.Email: xuzhihong@tamu.edu

Abstract

Technology is increasingly being integrated into classrooms worldwide to enhance learning outcomes, and simulation technologies are becoming more popular to create realistic scenarios in controlled academic settings. However, simulation studies in agricultural education have been limited, making it difficult to assess the impact of simulation technologies on student learning. To address this literature gap, a systematic literature review of 17 articles was conducted to examine the use of simulation technology in agricultural education. The analysis revealed that simulation technologies were most used in agricultural science sub-disciplines that involve experimentation and practical application. Most studies focused on undergraduates and utilized quantitative research methods, with virtual and augmented reality being the most commonly employed types of simulation. Positive effects of simulation on learning outcomes were reported in most studies, including improved academic achievement, psychological factors such as anxiety, and tracking students' progress. However, the technology's time-consuming nature and potential for uncomfortable physical conditions like cybersickness were identified as demerits. More rigorous standards were recommended to improve reporting procedures in agricultural education studies with simulation technologies.

Keywords: agriculture, educational technology, learning outcome, simulation

In agricultural education, educators continuously seek efficient teaching methods that promote student engagement and enhance their skills in utilizing predictive, computer-based, and data-driven tools for effective consultation and decision-making (Basche et al., 2021). Due to this, classrooms have witnessed a rise in the utilization of diverse technologies (Grzybowski, 2013; Lee et al., 2022; Xu et al., 2021). Among these technologies, simulation stands out as an effective tool that recreates real-life situations in a controlled learning environment. By using simulation, students can better grasp agricultural concepts and significantly improve their critical thinking and decision-making skills (Agnew & Shinn, 1990; Ibendahl, 2017; Klit et al., 2018; Petrás, 2020).

Several authors have defined simulation as the reproduction of real-world processes or systems in a controlled environment (Banks, 2000; Bobillier et al., 1976; Gaba, 2004; Maria, 1997; Zeigler, 1976), which can offer a transformative tool for experiential learning in agriculture (Klit et al., 2018; Koontz et al., 1995; Lamm et al., 2011). Its immersive virtual environments that mimic farming contexts offer diverse learning opportunities. Simulation also enables students to comprehend complex concepts (Anderson, 1984; Briggeman et al., 2012; Bunch et al., 2014), navigate various scenarios (Blank, 1985), and make informed decisions (Van Dam et al., 1997). By simulating different farming methods, environmental scenarios, and crop management tactics, simulation technology has the potential to transform agricultural education and prepare students for future challenges.

While simulation has been extensively studied and utilized in diverse educational fields (simulation studies in general/other fields), its specific application remains relatively understudied, especially the overall impact on learning outcomes in agricultural education needs to be more studied. To bridge this research gap, our systematic literature review aims to provide an in-depth analysis of the effectiveness and practicality of simulation as an educational technology in the agricultural domain. By thoroughly examining a wide range of research papers, we seek to offer a comprehensive understanding of both the benefits and challenges associated with integrating simulation into agricultural curricula.

Through our review, we aim to shed light on how simulation can be effectively employed in agricultural education, helping educators and stakeholders make informed decisions about its implementation. By identifying the strengths and weaknesses of simulation-based learning approaches, we hope to pave the way for more tailored and impactful use of this technology in agricultural classrooms. Ultimately, this study aims to significantly contribute to the field of agricultural education by delineating how educators and students can be better equipped to face the complexities and demands of the ever-evolving agrarian landscape.

Simulation as a Form of Educational Technology

According to Ely (1999), the primary goal of incorporating educational technology in the classroom is to bring about meaningful transformation. These transformations include the stimulation of effective learning and improvement in performance (Sakat et al., 2012), and enhancement of skills and cognitive characteristics (Lazar, 2015). Simulation as a type of educational technology (ET) plays a crucial role in addressing the shortcomings of traditional teacher education programs because classroom training for pre-service teachers often prioritizes lesson planning over understanding student behavior and functioning (Darling-Hammond, 1999; Ramsey, 2000), leading to gaps in learning and preparation (Bradley & Kendall, 2014). To address these challenges, teacher preparation programs have been prompted to offer opportunities for pre-service teachers to observe and participate in decision-making processes (Cambourne et al., 2003; Groundwater-Smith et al., 1996). However, time and resource constraints can make providing such opportunities in typical academic environments challenging.

Vlachopoulos and Makri (2017) attempted to distinguish between digital games and simulations clearly. They explained that games are artificial and educational tools that involve rules, conflict, and predetermined objectives. On the other hand, simulations are dynamic tools that aim to represent reality and claim fidelity, accuracy, and validity. Another grey area is between VR and simulation. Thurman & Mattoon (1994) said that VR is a type of interactive simulation that includes the human user as a necessary component. These distinctions have become necessary owing to the prevalence of studies that either lump the two together or use them interchangeably, and this is further affirmed by Suave et al. (2007).

Lunce (2006) and Alessi &Trollip (2001) stated some advantages of simulation technology over other forms of instructional methodologies and media, including active participation, which is more interesting, intrinsically motivating, and closer to reality. Simulation has also been more effective in transferring learning, ensuring optimum performance in real-world settings (Leemkuil et al., 2003). Simulation enables active participation, experimentation, and experiential learning by immersing learners in safe yet realistic settings. This approach allows students to apply theoretical concepts to real-life situations, make informed decisions, assess outcomes, and refine their abilities without facing real-world consequences (Alessi & Trollip, 2001; Leemkuil et al., 2003).

Lunce (2006) highlighted several drawbacks of simulation technology, as noted by other researchers. These include the significant time investment required by the problem-based learning approach (Duffy, 1996). Additionally, there is a need for extensive coaching, scaffolding, feedback, and debriefing. Without these elements, learners might see simulations merely as games, and this may lead to minimal learning, a concern echoed by Duffy (1996), Heinich et al. (1999), Leemkuil et al. (2003), and Min (2002). Another argument often given is that simulation over-simplifies real-world problems, causing the learners to not thoroughly appreciate how those problems exist in the real world (Heinich et al., 1999). The cost of purchasing, learning, operating, and maintaining these technologies has also often been highlighted in the campaign against their use.

Core Concepts and Applications of Simulation in Agricultural Education

To effectively utilize simulation technology in agricultural education, educators must grasp critical concepts such as realism, interactivity, adaptability, and transferability. These factors allow for tailoring the simulation experience to specific learning objectives and preparing students for real-world agricultural contexts (Bland & Tobbell, 2016; Goodyear et al., 1991). Simulation technologies are used in agricultural education to train students in areas such as crop management, livestock husbandry, and soil conservation. These tools simulate real-world scenarios, providing a safe environment for students to practice their skills and develop expertise for success in the agricultural industry. Farm management simulators (Attonaty et al., 1999; Cros et al., 2003; Le Gal, 1997) allow students to manage a virtual farm by making managerial decisions such as crop selection, livestock management, etc. On the other hand, crop growth simulators expose students to scenarios of factors that may affect the growth of crops, such as weather and soil conditions, fertilization, and irrigation (Boote et al., 1998; Palosuo et al., 2011; Spitters & Schapendonk, 1990). Simulation technology has also been deployed in other fields of agricultural education, such as livestock production (Kim et al., 2019; Maonga & Mapemba, 2014; Xia et al., 2022), agricultural mechanics (Agnew & Shinn, 1990; Doss et al., 2019; Wells & Miller, 2020), and pest and disease management (Ginajar w, 2012; Saunders & Cox, 2014).

Previous Reviews

Numerous systematic reviews have examined the impact of using educational technology (ET) on enhancing learning outcomes in pure and applied educational sciences. For instance, Asad et al. (2021) explored how virtual reality could improve experiential learning, Ummihusna & Zairul (2021) examined the use of immersive learning technology in architectural education, Amara et al. (2016) studied how groups are formed in mobile computer-supported collaborative learning contexts, and Ullah et al. (2022) evaluated the deployment of digital games in science education. There have been a few reviews that have solely examined the use of simulation. For instance, Theelen et al. (2019) conducted a study focused on simulations in teacher education. They analyzed 15 studies included in their review. They discovered that simulation technology positively impacted preservice teachers' general classroom management and teaching skills rather than just interpersonal competence. The researchers pointed out that the success of the learning experience was contingent on the level of realism and authenticity within the simulation. A recent review by Nikolic et al. (2021) delved into the effectiveness of simulation in education, comparing remote, simulation, and traditional laboratory scenarios. Their study found that assessments tend to only focus on the cognitive domain, which only partially captures the extent of learning achieved. Additionally, survey instruments were shown to be crucial in accurately measuring learning outcomes.

Although Bulut & Wu (2023) aimed to examine the Internet of Things (IoT) use in agriculture, their review did not cover the sub-discipline of agricultural education. The only study that focused on this area was conducted by Vickrey et al. (2018). While this study provided valuable insights into educational technologies and instructional practices in agricultural sciences, with a particular emphasis on the technological pedagogical content knowledge (TPACK) framework, it did not specifically address simulation. Therefore, this systematic review is timely as it aims to fill this gap and investigate the types of simulation technologies utilized, their application, and their impact on students' learning outcomes.

The use of simulation technology in agricultural education is based on David Kolb's (2014) experiential learning theory. This technology offers students immersive and realistic experiences that allow them to learn through direct participation without risks. Virtual farm environments, crops, and livestock provide students with hands-on experience. They are encouraged to reflect on their actions, critically analyze their decisions, and identify improvement areas. By connecting these experiences with theoretical knowledge, they develop conceptual frameworks that deepen their understanding. Through active experimentation and analysis of outcomes, students can enhance their critical thinking skills and practical expertise in a safe environment. Simulation technology is an asset in agricultural education.

Purpose and Research Questions

The purpose of this systematic literature review was to critically examine the use of simulation technology in agricultural education with an emphasis on learning outcomes. We examined the following aspects of the existing literature: 1) Substantive and methodological features; 2) Characteristics of simulation in agricultural education; 3) Simulation benefits and challenges. The research questions that guided the study were:

- What are the substantive and methodological features of the included studies, such as publication information, research, and data collection methods?
- What are the characteristics of simulation technology used in agricultural education, such as simulation technology types, intervention characteristics (duration and intensity), and the benefits and challenges?
- What is the impact of simulation technology on students' learning outcomes?

Methods

Search Strategy

We developed a thorough search strategy that included key search terms. We searched through five databases (CAB Abstracts, AGRICOLA, ERIC, Education Source, and Web of Science for Collection) for articles published between January 2000 and September 2022. Our search identified two main concepts: simulation technology and agricultural education, resulting in 3,737 articles. We used Covidence, a screening and data-extraction tool for conducting systematic reviews to screen these articles. 643 duplicates were removed, leaving 3,094 articles that were screened for eligibility. After reviewing the abstracts and full texts based on our inclusion and exclusion criteria, we found only 19 articles suitable for coding. During the coding stage, we excluded two articles due to insufficient data or not meeting the inclusion criteria. This reduced the number of included articles to 17 (Fig 1).

Inclusion and Exclusion Criteria

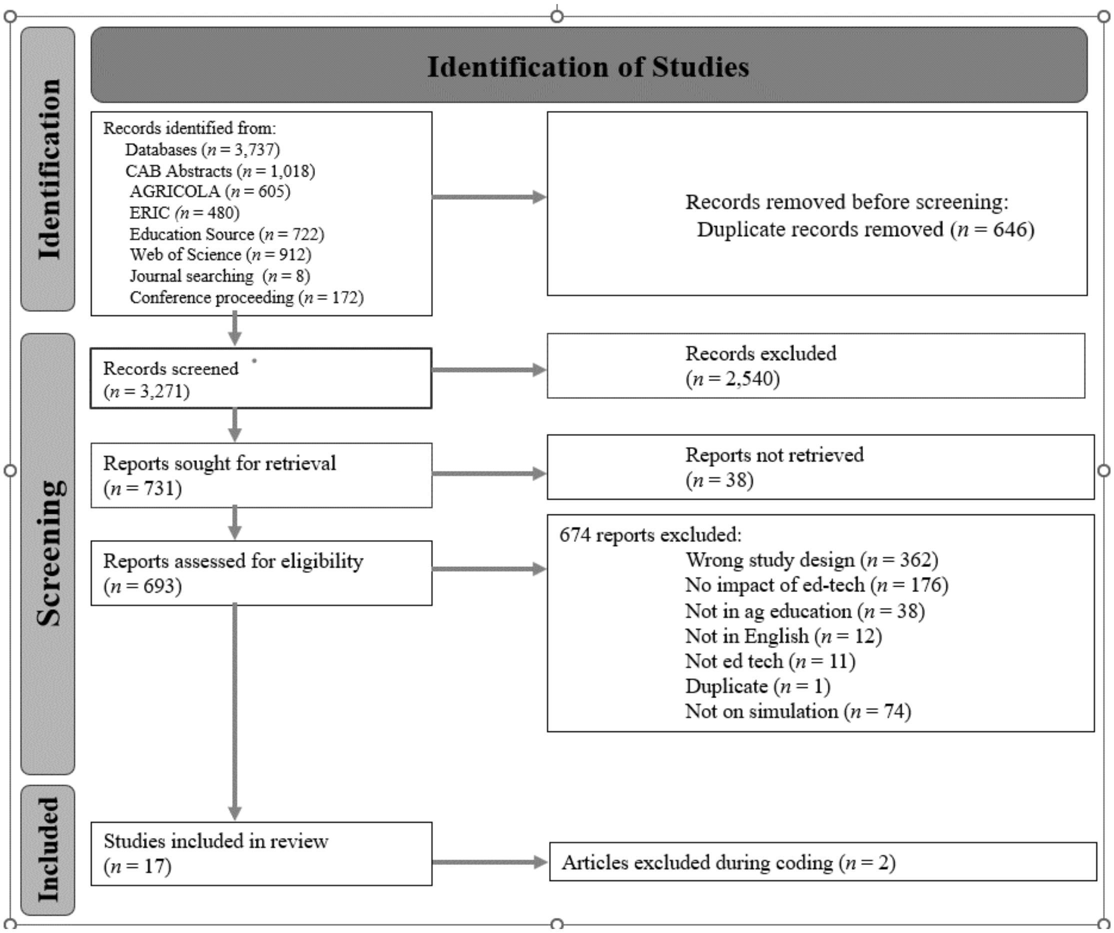
To be included in this systematic review, selected studies must have met several conditions: they must analyze the impact of simulation on agricultural education, be published in a journal, conference proceeding, or thesis between 2000 and 2022, and must detail the assessment methods used to measure simulation's impact on agricultural education. Additionally, these studies must provide information on sample size, experimental design, and specific results regarding the simulation’s effect on agricultural education. Articles containing measurable learning outcomes, such as academic performance results, final scores, and other detailed learning outcomes, were also included.

Coding Scheme

We created a thorough and detailed coding system to help us organize the studies and extract data more efficiently. Our

Figure 1

PRISMA flow diagram



coding form systematically covers the studies' substantive and methodological aspects, including subjects, educational level, research methods, data collection approaches, instruments used, and sample sizes. Additionally, we included information on the types of simulation used in agricultural education, intervention characteristics, and the effects of simulation on learning outcomes. A summary of the included studies is shown in Table 1 below.

Subjects

We categorized subjects according to their specific agricultural sub-disciplines, including agricultural science (practical sciences related to agriculture), agricultural engineering, agricultural leadership, education and communications (ALEC), agricultural economics, and finance. We also used "mixed" for studies involving more than one subject and "unspecified" for those not clearly stating their discipline.

Educational Level

Educational levels were categorized as secondary (7-12), undergraduate, graduate, professional/certificate/adult learners, mixed for studies that combined multiple educational levels, and unspecified for those that did not specify.

Research Methods

These were categorized into quantitative, qualitative, and mixed methods for studies that used both.

Data Collection Approaches

These were classified as surveys/questionnaires, interviews, test assessments/examinations, homework assignments, and GPAs.

Type of Simulation

The studies categorized the types of simulation used into computer-based simulation, virtual/augmented reality, digital game-based simulation, and interactive/online simulation.

Intervention Characteristics

We coded the intervention characteristics under the intervention's duration and intensity. We used a cutoff point of 75 minutes (Cheung & Slavin, 2012) to categorize the intervention intensity into strong (>75 minutes) or weak (<75 minutes). We also coded the duration of the intervention using a cutoff point of three months into long (> 3 months) or short (< 3 months) based on Chaudhry & Al-Haj (1985).

Effect of Simulation on Learning Outcomes

Learning outcomes were categorized as positive, negative, non-significant, or mixed.

Table 1

Summary of included studies

Article	Subject	Educational level	Research methods	Effect of Simulation on learning outcome
Boyd et al. (2002)	ALEC	Undergraduate	Quantitative	Positive
Garza et al. (2022)	Agricultural engineering	Undergraduate	Quantitative	Mixed
Briggeman et al (2012)	Agricultural Economics & Finance	Undergraduate	Quantitative	Positive
Heibel et al. (2022)	Agricultural engineering	Undergraduate	Quantitative	Positive
Heibel et al. (2021)	Agricultural engineering	Undergraduate	Quantitative	Positive
Bunch et al. (2014)	ALEC	Secondary	Quantitative	No statistically significant impact
Davis et al. (2012)	Agricultural science	Undergraduate	Quantitative	Positive
Klit et al. (2018)	Agricultural science	Undergraduate	Quantitative	Positive
Hasselquist et al. (2021)	ALEC	Undergraduate	Qualitative	Mixed
Garza et al. (2022)	Agricultural engineering	Undergraduate	Quantitative	Mixed
Perry & Smith (2004)	Agricultural science	Undergraduate	Quantitative	Positive
Strong et al. (2022)	Agricultural science	Undergraduate	Mixed	Positive
Trifan (2011)	Agricultural science	Undergraduate	Quantitative	Positive
Wells & Miller (2022)	Agricultural engineering	Undergraduate	Qualitative	Mixed
Wells & Miller (2020)	Agricultural engineering	Mixed	Quantitative	No significant impact
Wery & Lecoeur (2000)	Agricultural science	Undergraduate	Quantitative	Positive
Witt et al. (2011)	ALEC	Graduate	Quantitative	No significant impact

Results and Discussion

Substantive and Methodological Features of the Studies

Subjects

Out of the 17 studies that were analyzed, it was found that simulation technologies were most used in the field of agricultural sciences (n = 7, 41.2%), followed by agricultural engineering (n = 6, 35.3%). ALEC had the third highest use of simulation technologies (n = 3, 17.6%). Only one study (5.9%) reported the use of simulation in agricultural economics and finance. This suggests that agricultural sub-disciplines were more inclined towards the sciences, involving experimentation and practical application, and may be more likely to utilize simulation technologies than social sciences like ALEC, agricultural economics, and finance. Studies like those of Klit et al. (2018), Perry & Smith (2004), and Webb et al. (2015), for instance, all focused on the use of simulation in the animal science field.

Educational Level

Figure 2 reveals that most studies (76.47%, n = 13) were conducted at the undergraduate level. Two studies (11.76%) encompassed two distinct educational levels. Only one study was conducted at the secondary and graduate levels (5.88% each).

Research Methods

Figure 3 shows that the quantitative method was the most used (n = 14, 82.4%). While two studies (11.8%) employed the qualitative approach, only one study (5.9%) used the mixed-method approach. Among the included quantitative studies, various research designs were identified, including a three-arm cohort study with negative and positive control groups (Klit et al., 2018); pre-post tests (Briggeman et al., 2012; Witt et al., 2011); a randomized posttest-only design (Wells & Miller, 2020); and a quasi-experimental design (Bunch et al., 2014). Meanwhile, one of the two qualitative studies (Webb et al., 2015) employed a case study approach. There appears to be an advocacy for the increased use of mixed-methods research approach (Molina-

Azorin & Guetterman, 2023; Pantic et al., 2023; Snodgrass et al., 2023), but how this can become more integrated into simulation researchers in the field of agricultural education could be a subject of interest in the future.

Data Collection Approaches

Various methods were employed in the studies to collect data. Seven studies (41.2%) utilized interviews, test assessments, examinations, homework assignments, and GPA. Mixed methods were used in five studies (29.4%), while surveys and questionnaires were used in four studies (23.5%). Only one study (5.9%) employed a focus group approach. These data collection tools were mainly created by researchers to cater to the specific needs of the intended data collection.

Characteristics of Simulation in Agricultural Education

Types of simulation. Among the four types of simulations, virtual/augmented reality (n = 9, 52.94%) is the

Figure 3

Research Methods

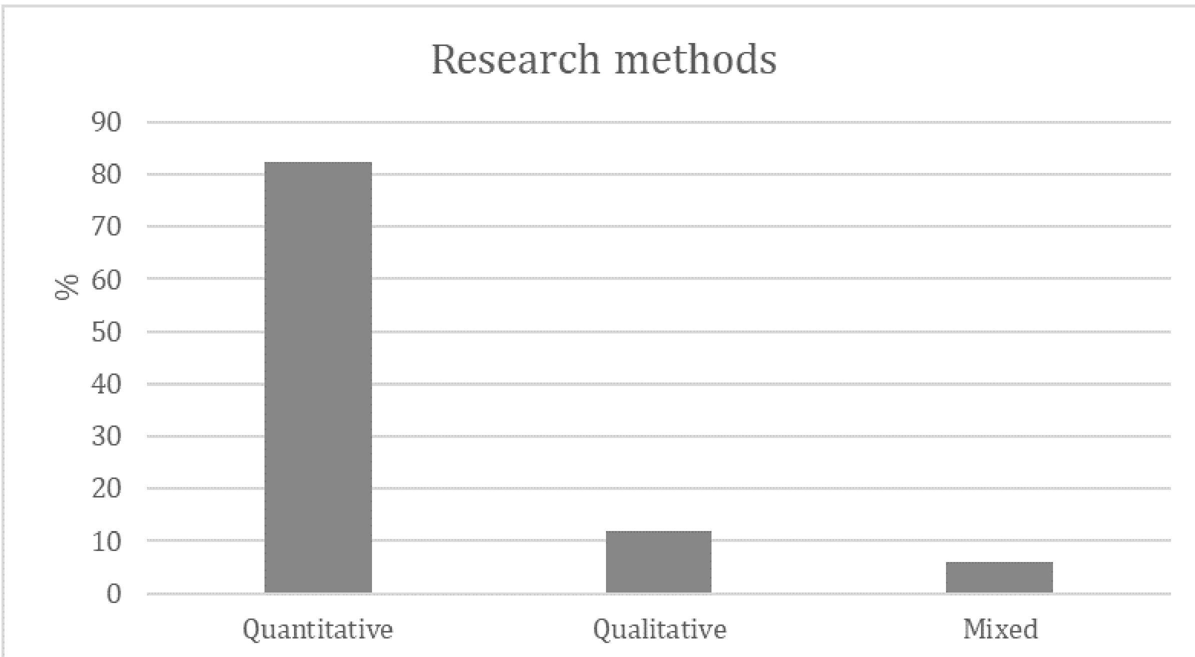
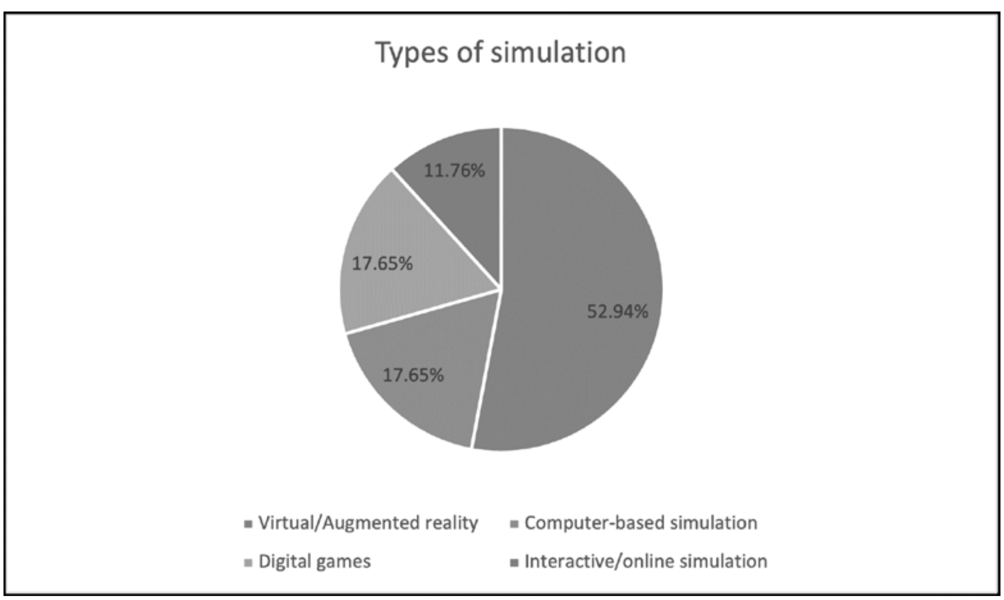


Figure 4

Types of Simulation



most frequently used in our seventeen included studies, followed by computer-based simulation (n = 3, 17.65%) and digital games (n = 3, 17.65%). The least utilized type is interactive/online simulation (n = 2, 11.76%). These findings suggest that virtual/augmented reality is highly suitable for agriculture education. For instance, six studies employed virtual/augmented reality in welding for agricultural purposes.

Intervention Characteristics. Among the 17 studies, 11.76% (n = 2) did not specify the duration information, while 35.29% (n = 6) implemented long durations (3 months or more), and 52.94% (n = 9) used short durations (less than three months). These findings suggest that most studies in agriculture education tend to favor short-term durations.

Regarding Intensity. 23.53% of the studies (n = 4) employed strong-intensity sessions lasting more than 75 minutes, and 76.47% (n = 13) did not report intensity information. Most studies should have provided information about the intensity, highlighting the need for future studies to include implementation details, such as intensity levels.

Effect of Simulation. Most of the studies reported positive effects (n = 11, 64.71%), followed by non-significant results (n = 4, 23.53%) and mixed results (n = 2, 11.76%). These findings indicate that the use of simulation/digital games is effective and has a positive impact on learners in the majority of the studies.

Simulation Benefits and Challenges

Based on the concept of constructivism, the use of educational technology highlights the importance of acquiring knowledge through active engagement, learning, and real-world application (Jumaat et al., 2017). Previous studies have shown that simulations and digital games offer numerous benefits, including increased motivation (Sotiriou & Bogner, 2008), facilitation of cognitive learning skills (Sotiriou & Bogner, 2008), enhancement of critical thinking skills, problem-solving abilities, and cooperative communication skills (Dunleavy et al., 2009), provision of feedback (Zhou et al., 2008), and improvement of learning achievement (Xu et al., 2022).

Improved Students' Learning Achievement, Simulation and digital games can replicate real-world problems using multimedia replicas such as images, video, 3D environments, and animations. These technologies target higher-order cognitive skills, including critical thinking, problem-solving, and application of knowledge, fostering creative thinking skills. For example, educational technology can present intricate information, enhancing students' creativity by integrating technology into various creative processes (Liu et al., 2022).

In our included studies, some provided evidence of improved knowledge and skills. Trifan (2011) demonstrated that virtual laboratories helped students better understand topics in soil science. Davis et al. (2012) highlighted the role of educational technology in providing lifelike experiences in realistic environments. As Bloom et al. (1964) suggested, experiential learning can enhance students' cognitive learning). Hence, simulations can promote cognitive skills by simulating real-world learning experiences. For instance, a game-based virtual reality simulation for farrowing management aided low-performing Danish agriculture students in developing essential pig farming skills, reducing piglet mortality (Klit et al., 2018). Moreover, Briggeman et al. (2012) also investigated an internet-based agricultural bank simulation game, which improved students' understanding of finance, economics, and banking concepts in a virtual environment. Computer-based simulations enhanced students' leadership concepts and enabled the real-world application of knowledge (Boyd & Murphrey, 2002). Virtual field practice allowed participants to develop acute teaching knowledge, teacher identity, and self-efficacy (Hasselquist et al., 2021). Several studies demonstrated the benefits of using simulations for welding, such as virtual reality welding systems helping students gain practical welding skills (Wells & Miller, 2022) and improved performance due to visual and auditory parameter cues aiding comprehension of complex skills (Heibel et al., 2022). Moreover, simulation can facilitate skill acquisition by guiding learners to the automatic stage in skill acquisition theory, encompassing declarative, procedural, and automatic stages (DeKeyser, 2015).

Higher-order thinking skills are vital in learning, and situational simulations allow students to engage in activities resembling real-life situations. Bloom's hierarchical categories proposed six cognitive levels: knowledge, comprehension, application, analysis, synthesis, and evaluation (Bloom, 1956). Some studies strongly support how simulations and digital games influence higher-order thinking skills. For instance, Boyd & Murphrey (2002) found that the treatment group scored significantly higher on cognitive levels, particularly analysis, compared to lower levels like knowledge and comprehension. Perry & Smith (2004) suggested that reproductive simulation exercises in the reproductive management project facilitated the development of critical thinking, problem-solving, and creativity.

Students' Psychological Factors: Simulation and digital games can positively influence students' psychological factors, including motivation, attitude, and engagement. These technologies actively engage learners through sensory interactions, leading to improved knowledge retention, a better understanding of abstract concepts, and memory retention (Garzón et al., 2019). Firstly, simulations and digital games can increase motivation by providing competitive and fun experiences. This, in turn, helps students reach their optimal psychological states by maintaining an appropriate level of anxiety, self-efficacy, and comfort.

Scholars have previously indicated that educational computer games effectively mimic motivational aspects (Gee, 2003; Virvou et al., 2005). Digital games have shown to increase students' motivation, with interpersonal competition promoting positive attitudes (Ke & Grabowski, 2007; Byun & Young, 2018). Our included studies also showed that games were enjoyable and fun, enhancing student participation and interest (Briggeman et al., 2012). Trifan (2011) mentioned that virtual labs in agronomy made learning enjoyable and motivating. Perry & Smith (2004) indicated that a competitive atmosphere was created through the reproductive simulation exercise, increasing students' enthusiasm and desire for deeper understanding through competition.

Secondly, simulations and digital games can reduce anxiety and increase self-efficacy, allowing students to be more relaxed and comfortable while focusing on tasks. Our included studies revealed that simulation groups scored significantly higher in self-efficacy, particularly in choosing the correct antibiotics for piglet injection. Additionally, the hands-on group experienced increased anxiety and reduced self-efficacy without proper preparation (Klit et al., 2018). Simulation games are instrumental in reducing procedural task anxiety. For example, they prepare students for performing surgical procedures on live animals and mitigate performance-related anxiety in tasks such as welding (Byrd, 2014). Virtual reality provides a less stressful learning environment, enhancing skill development (Wells & Miller, 2022). For instance, VR welding quelled anxious students' fears, especially for first-time users, offering a safe and controlled virtual environment for agriculture practice (Heibel et al., 2022).

Improved Instruction. Effective teaching encompasses four factors: the quality of instruction through clear and well-organized lessons, the proper level of instruction tailored to individual learners' difficulty level and learning rates, incentives that motivate students, and sufficient time for adequate instructional sessions (Cheung & Slavin, 2012). Simulation and digital games actively improve teaching by incorporating these four aspects of learning. Computer technology allows for sufficient practice and feedback, which enhances learning quality (Cheung & Slavin, 2012). Our findings reveal three common themes in incorporating simulations and digital games in education: providing instant feedback, promoting student engagement, and offering personalized learning for better instructional quality.

First, simulation and digital games offer instant feedback. In our included studies, Klit et al. (2018) pointed out that game-based learning is active, experiential, and problem-based, providing immediate feedback. Several studies explored the instant feedback function in welding. Heibel et al. (2022) revealed that personalized feedback from virtual welding simulators enhances learners' skill acquisition (Heibel et al., 2022). Wells & Miller (2022) suggested that virtual reality welding provided adequate feedback using visual cues. Another study investigated welding processes using an Augmented Reality Welding system, where arc-on mode provided instant prompts/feedback, facilitating meaningful learning (Garza et al., 2022). Personalized feedback, scaffold visual and auditory cues, simulation, and digital games help learners develop welding performance skills (Heibel et al., 2021).

Second, simulation and digital games promote student engagement and active participation, transforming the teacher's role. Our included studies indicated that constructivism emphasizes individual learners' focus and problem-solving abilities (Bunch et al., 2014). Davis et al. (2012) highlighted that using iFARM increased student involvement, and game-based learning allowed interaction with other users, fostering a learning community.

Third, simulation and digital games enable tracking of students' progress and performance, facilitating self-paced learning and evaluation and resulting in personalized learning experiences. Moreover, simulations and digital games support differentiated learning based on students' previous knowledge and learning rates, catering to diverse learners in a self-paced environment that allows autonomy in learning. Personalized learning has been shown to improve learning outcomes (Arroyo et al., 2014), and technology is crucial in supporting personalized learning (Major et al., 2021). In our included studies, VRTEX 360 tracked users' welding performance (Heibel et al., 2022). Trifan (2011) demonstrated easy tracking of long-term experiences and opportunities for independent exploration, and self-assessment tests were embedded in virtual laboratories. According to Wery and Lecoeur (2000), computers assist students' thinking processes.

Two types of personalized learning systems were proposed: responsive and adaptive personalized learning systems (Bulger, 2016). While responsive systems allow learners to understand if their responses/feedback are correct, future studies can focus more on adaptive, personalized learning systems, allowing learners to choose tailored learning paths and adapting content delivery based on learner behavior or performance (Major et al., 2021). Future research in the agriculture field should focus on incorporating personalized learning content and paths into simulation and digital games.

Cost, Accessibility, and Flexibility: simulation and digital games offer low cost, great accessibility, and flexibility. Wells & Miller (2022) acknowledged the benefits of saving consumable materials. Trifan (2011) mentioned that students can access materials at home and interact with teachers throughout the year, demonstrating the good accessibility and flexibility of virtual laboratories. Although VRTEX 360 VR welding training simulators may have high upfront costs, funding opportunities can help resolve this issue. Moreover, VR is cost-effective as it allows multiple users to access the technology.

In summary, simulations offer four key benefits: enhancing students' learning achievements, influencing their psychological well-being, improving instruction, and providing advantages in low cost, accessibility, and flexibility.

Challenges. In agricultural education, simulations and digital games pose several hurdles, including the extensive amount of time devoted and the likelihood of physical discomforts, such as cybersickness. Briggeman et al. (2012) emphasized the substantial time students need for decision-making, while Wery & Lecoeur (2000) acknowledged the burden on students and instructors due to practical learning exercises. Additionally, technologies like virtual reality can lead to symptoms including headaches, dizziness, and motion sickness, with some studies documenting negative experiences like discomfort from wearing headsets and experiencing nausea (Strong & Palmer, 2022).

Given their inherent limitations, Bunch et al. (2014) highlighted that simulations should enhance, not replace, practical teaching. Beyond the challenges our included studies identified when using simulations, instructors and students might face other issues like the potential for game addiction, underscoring the importance of a balanced approach in using simulations. Additionally, creating new simulations or games in the absence of suitable existing options requires significant effort and time. Furthermore, the commercial nature of some simulations or games also introduces potential financial barriers for learners.

Conclusions and Recommendations

As agricultural challenges become more complex and the demand to sustain and enhance agri-food systems production grows (Talbert et al., 2022), educators in the field are seeking innovative strategies to prepare the next generation of professionals. Among these innovations, simulation technologies have emerged as particularly effective, significantly benefiting professional development in agriculture. However, deploying these simulation technologies is not without some challenges. This systematic review focused on the impact of simulation technologies within agricultural education, presenting particularly relevant findings as educational programs increasingly incorporate digital technologies into their offerings (Joshi et al., 2022).

Seventeen research articles were analyzed after a rigorous literature search, and an inclusion and exclusion protocol was implemented. In summary, the potential of simulation technologies in agricultural education and other disciplines lies in the possibility of offering students experiences that simulate real-life scenarios, which would be unattainable if it were not for these technologies (Jonson, 2010; Wells & Miller, 2020; Pulley et al., 2023). Virtual/augmented reality was the most commonly used simulation technology in the studies analyzed in this review. This trend could be due to the versatility of this technology to adapt to the instruction and training of multiple simulation scenarios in a diversity of knowledge domains (Pulley et al., 2023). Following this thematic line, our results showed greater use of simulation technologies in the applied and biological sciences compared to the social and economic sciences.

The results of this study suggested that the educational outcomes of simulation technologies in agricultural education could be summarized into two categories: (1) critical thinking skills and (2) creative thinking skills. Similar learning outcomes have been associated with simulation technologies in teaching disciplines such as medicine (McGaghie et al., 2006; Okuda et al., 2009; Wang, 2022), nursing (O'Donnell et al., 2014), and business education (Clarke, 2009).

However, simulation technologies bring new challenges for agricultural educators. We identified the time-consuming nature of simulation and uncomfortable physical symptoms experienced by users as the main challenges for implementing simulation technologies in agricultural education. Our results are consistent with those of Pulley et al. (2023), who interviewed high school agricultural education teachers about their experiences using virtual reality in mechanical agriculture courses. Teachers mentioned that when using simulation technologies, they had to be more efficient in managing their resources, including time, and they assured that, although students experienced dizziness, it did not cause any of them to drop out. Additionally, teachers highlighted their need for more training on simulation technologies in agricultural education. Despite the challenges, this review identified the ease of offering feedback, promoting student engagement and active participation, and enabling tracking student progress and performance as mechanisms by which simulation technologies strengthen agricultural sciences instruction.

Regarding the methodological aspects, this systematic review highlighted the need to promote more rigorous standards in reporting procedures in agricultural educational studies with simulation technologies. Although some studies detailed the procedures and methods implemented, others present information gaps that limit results verification or study replicability in other academic contexts or knowledge domains. Additionally, quantitative performance results or qualitative results on user experiences have the potential to inform the educational community. However, some studies fail to present/describe the results of detailed learning outcomes. A mixed methods approach would allow comprehensive exploration of simulation technologies in agricultural education, allowing students' performance and perceptions/experiences to be integrated when researching learning outcomes.

Our findings are intended to inform other researchers and educators about simulation technologies and their potential in agricultural education while offering insights into current gaps in the literature on simulations as educational resources. To achieve these goals, we recommend to continue researching simulation technologies in agricultural education through two lines of inquiry: (1) at the academic levels (e.g., high school and postgraduate) and (2) in the domains of knowledge (e.g., social and financial sciences) for which information remains limited. Although, this study did not consider the integration of pedagogical theories as a categorization parameter. Other reviews on simulation technologies have highlighted the need to promote studies based on pedagogical reasoning (Kavanagh et al., 2017). Therefore, future research should integrate simulation technologies into teaching and learning studies rooted in solid pedagogical foundations to strengthen agricultural educational systems and pedagogical literature in agricultural education.

Finally, administrators and leaders in agricultural education must implement mechanisms that promote simulation technologies as a resource to enhance the competitive development of agricultural professionals. These mechanisms include but are not limited to assuring adequate resources, offering professional development opportunities for agricultural teachers, and promoting lessons tailored to local needs and opportunities (Pulley et al., 2023). In doing the latter, agricultural educators must consider the resources available and the characteristics of the student communities they plan to instruct using simulation technologies.

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