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Systematic Review

A Systematic Review of the Emergence and Utilisation of Agricultural Technologies into the Classroom

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Abstract: This systematic review explores the emergence and utilisation of agricultural technology ("AgTech") in secondary schools globally. A total of 14 studies published between 2000 and 2020, inclusive, were reviewed, each exploring the use of agricultural technologies in secondary school classrooms and barriers to adoption. For all reviewed studies, each had aimed to address one of three major objectives: (a) to determine or increase teacher knowledge of AgTech; (b) to evaluate the effectiveness of AgTech professional development (PD); or (c) to evaluate the effectiveness of AgTech classroom activities. Requirements for future AgTech PD or classroom activities were also identified, including the use of improved pre-service learnings and in-service PD. This study highlights the importance of improving the opportunities of teachers for AgTech learning, including both an introduction to the technologies and support for classroom implementation. Applications of these findings could be used by teachers, schools, industry organisations, universities and policymakers to ensure sufficient teacher knowledge and skills for effective student learning. By increasing the knowledge and skills of the next-generation agricultural workforce, it is anticipated that AgTech adoption on farms will increase.

Keywords: precision agriculture; capacity building; agricultural literacy; secondary school students; primary school students; agricultural education

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1. Introduction

Increased agricultural production to meet the needs of a world population of 9.7 billion by 2050 [1] will require the adoption of new practices to increase yield and manage inputs to support sustainable growth and efficiency. To do so, innovations in agricultural technology ("AgTech") to revolutionise current processes in order to increase production and profits will need to occur, alongside animal welfare and environmental sustainability considerations. There is no consensus on a definition of AgTech, though it includes the use of drones, artificial intelligence, precision livestock farming sensors, yield mapping, biotechnology and gene editing as a tool for the achievement of 'Precision Agriculture'.

Precision Agriculture, defined by the International Society for Precision Agriculture (ISPA), refers to:

> "A management strategy that gathers, processes and analyses temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production" [2].

Innovative technology development to support agriculture has undergone rapid expansion in the past decade and will contribute to the digital disruption of the industry [3,4].

AgTech has both financial and ethical incentives through the potential to improve efficiencies in labour and resource allocation, improve input and product traceability to satisfy consumer demand and support claims related to environmental and animal welfare [5–8]. AgTech adoption is critical in both existing agricultural businesses and new industry entrants, but will depend on the producer's adaptive capacity which is influenced by demographics (age, education), technical skills, internet access, cost and knowledge of available technology options [9–12]. In particular, low digital literacy skills and a lack of knowledge by producers of available AgTech options suitable for their purposes need to be overcome to enable agricultural businesses to harness the benefits of the technology and interpret the data output to aid in decision making [9,11].

Future roles in agriculture will require those new entrants to the industry to have well-developed agricultural knowledge coupled with the skills to work with both the technologies themselves and the significant quantity of data they generate [9]. The initial engagement with AgTech within the school setting is seen as important to both foster an understanding of the high-tech future of agriculture and to expose students to potential technology methods and practices to encourage the uptake of career pathways into the industry [12]. These digital skills should be incorporated at all levels of schooling, from primary to tertiary education, and ensure that they are representative of emerging and future agricultural workforce requirements rather than perpetuating historical stereotypes. Lesson plans incorporating agriculture should "transform the mundane perception of traditional farming and show new opportunities" [13], and reinforce that the digital age of agriculture will not require all industry employment to be in regional or remote areas [12] or available to those only from an agricultural background.

The purpose of this review is to develop an understanding of the emergence and current utilisation of AgTech in secondary school agricultural education programmes across the globe to inform future research, initial teacher education, innovations in practice and interdisciplinary collaborations. This builds on previous research on the agricultural literacy of primary and secondary school students globally [14]. The following research questions (RQ) were developed to evaluate the literature:

1. What type of research into the use of agricultural technologies in secondary school classrooms has been conducted globally?
2. What findings and conclusions were produced?
3. What are the barriers to utilising agricultural technology in secondary school agricultural education programmes?

This review outlines the method used, presents the results on the identified empirical studies which examine agricultural technology use by secondary school students and/or teachers, discusses the major themes identified in the literature and provides recommendations for future research.

2. Methods

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol [15] was adapted to provide the transparent method for literature selection for analysis. Reputable scholarly sources were identified and screened to determine eligibility according to key words and inclusion criteria. Relevant studies were retained for detailed analysis and an analytic matrix was established.

Reputable sources included databases (EbscoHost, Education Database, ERIC, ProQuest, Agricultural Science Database, Scopus and Google Scholar) and the key English language journals in the field (Journal of Agricultural Education and the Journal of Agricultural Education and Extension). Key words and phrases used in the searches were "agricultural technology/agtech/ag-tech/agri-tech/agritech" and "school*/student*/teacher*/education/professional development". These phrases were selected to capture agricultural technology literature related to schools, teachers and school-aged persons. The truncation option (*) allowed for identification of sources with multiple endings (e.g., school, schools, schooling).

Articles were required to meet all of the following criteria for inclusion:

1. Studies conducted on samples of school students, teachers or a combination of the two.
2. Empirical studies engaging with the concept of agricultural technology by secondary school students and/or teachers.
3. Studies conducted either within or outside of the normal school setting.
4. Peer reviewed research articles and conference proceedings published between 2000 to 2020, inclusive.
5. Published in the English language.

A schematic outline of this process is shown in Figure 1, including the phases of literature identification, initial screening to remove duplicates and eligibility assessment. Eligibility was first determined according to the inclusion criteria applied to titles and abstracts. After discarding those not eligible, a full-text reading of all remaining literature was conducted to determine those selected for detailed analysis. Four researchers undertook this task, with a peer review at each phase of the process.

The search generated 6247 articles for consideration. Elimination of duplicates was performed initially using Endnote X9 and secondly by manual review of author and title. After duplicates were removed, 3773 articles remained. Titles were reviewed to exclude 3077 articles as out of scope. Journal and conference websites were reviewed to remove 380 articles which were not subject to a peer review process or were incomplete records. Titles and abstracts of the remaining 316 studies were reviewed initially by two members of the research team to determine inclusion of full text review. When two could not reach consensus, a third reviewer was used to reach consensus for inclusion or exclusion. A total of 285 articles were removed at this stage. The full text for the 31 remaining articles were then retrieved and divided between three members of the research team for appraisal of quality using an adapted Critical Appraisal Skills Programme (CASP) checklist for qualitative research [16]. This checklist was selected to accommodate for multiple methodologies, including qualitative, quantitative and mixed methods approaches. This resulted in the exclusion of a further 17 articles.

The remaining 14 articles were read in full, and details were extracted to establish an analytic matrix for critique and interpretation: (i) author and year of publication; (ii) study problem and aim; (iii) research questions and objectives; (iv) research design including theoretical framework and methodology; (v) target population including location, number of participants, timeframe; (vi) methods of data collection, analysis process/es; (vii) ethical approvals and considerations; (viii) key findings and summary recommendations; (ix) implications for this review's questions and aim. Microsoft Excel was used to collate these findings. As not all criteria outlined above were provided in every article, gaps, where identified, were noted in the matrix.

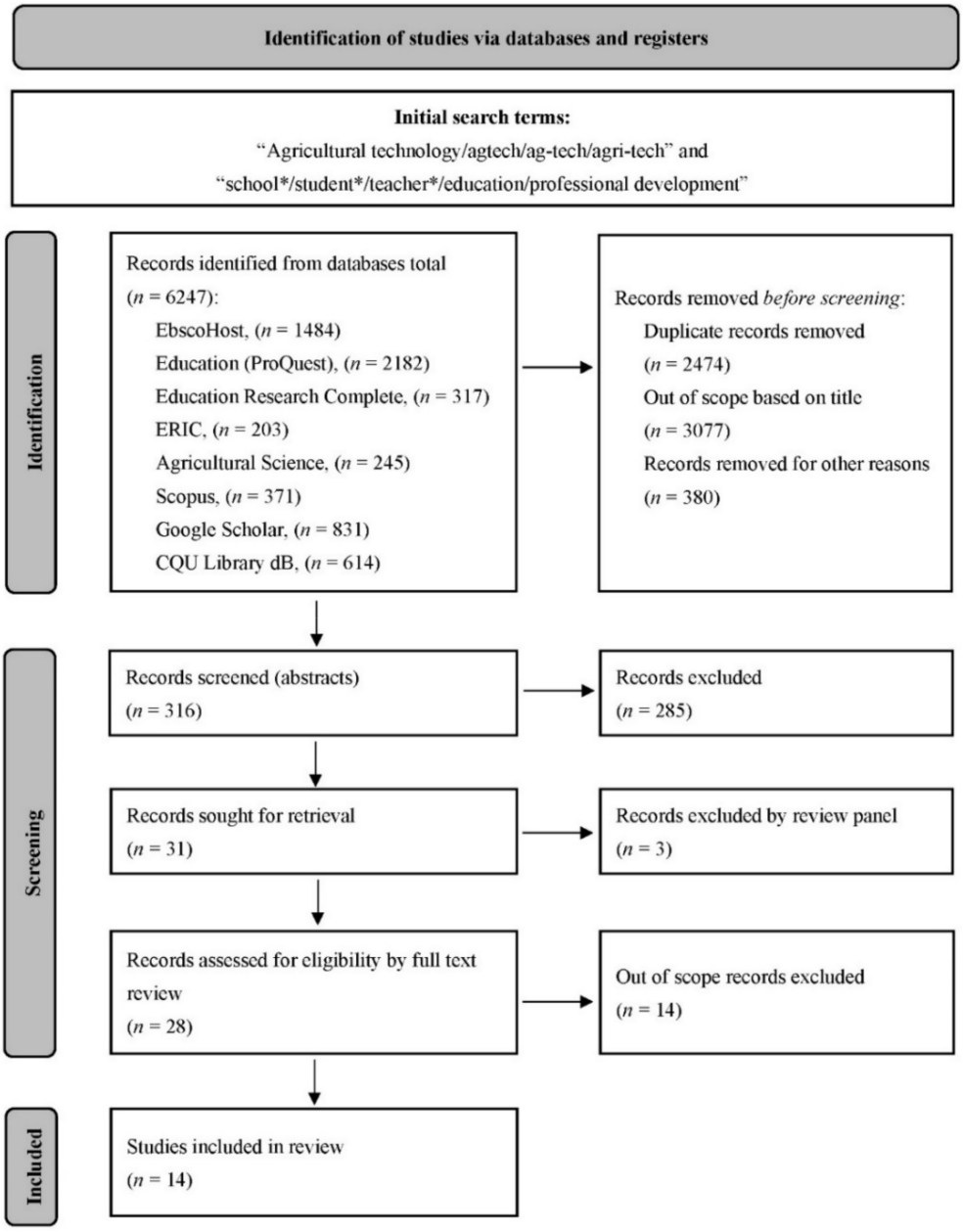

Figure 1. PRISMA Flow Diagram (Adapted from Page et al. 2021). * indicates search terms with multiple endings.

3. Results

The analytic matrix for all 14 full-text articles read by the research team is shown in Appendix A. For ease of interpretation, article details have been summarised to include author reference and location, purpose and/or aim of the research, methods (including data collection and analytical processes), sample size and participants, summary findings and recommendations relevant to this investigation of agricultural technology use by secondary school teachers globally.

3.1. RQ1: What Type of Research into the Use of Agricultural Technologies in Secondary School Classrooms Has Been Conducted Globally?

3.1.1. Aim/Purpose of Studies

The 14 included studies were reviewed and categorised into three main objectives: (a) to determine or increase the teachers' attitudes toward, knowledge or awareness of AgTech (n = 8); (b) to evaluate the effectiveness of teacher professional development

(PD) (n = 4); or (c) to evaluate the effectiveness of classroom activities to increase AgTech knowledge, attitude or capabilities of students (n = 3). One study, [17], was considered applicable to both (a) and (b).

Aim a: Determine or Increase Teachers' Knowledge, Awareness or Attitude towards AgTech

Eight studies sought to determine or increase the teachers' knowledge, awareness or attitude towards AgTech. Of these, three focused primarily on biotechnology as a subset of AgTech. Simonneaux [18] considered how teacher traits influence the knowledge and opinion of biotechnology and the tendency to engage with the technology. However, the study did not examine how biotechnology applications could be utilised in the curriculum. Wilson et al. [19] reviewed agriculture education (AgEd) teachers' perceived versus actual knowledge, and perceived the importance of the integrated science competencies needed to teach the state-developed "Biotechnology and Agriscience Research" course. Barriers to course adoption were also evaluated. Finally, Boone Jr et al. [20] sought to determine the relationship between teacher demographics, attitude and knowledge of biotechnologies. Biotechnology was the emerging agricultural-related technology of the early 2000s. In general, the later published studies reviewed in this paper involve a more extensive list of technologies which emerged in the following decade.

King et al. [21] focused on 15 new and emerging technologies appropriate to the agricultural industry, including precision agriculture sensors, and evaluated the adoption of these technologies into the curriculum and subsequent need for teacher PD. Smalley et al. [22] also considered the PD needs of teachers in some agricultural topic areas, including technical agriculture, though did not specifically consider teacher knowledge of AgTech. Weeks et al. [23] examined the perceptions and knowledge of AgEd teachers on 12 different 21st century learning skills (e.g., technology literacy, information literacy, communication, critical thinking) with the purpose of identifying PD needs to address this area. Earlier, Duncan et al. [24] sought to identify the in-service needs of AgEd teachers including their technology needs. Cosby et al. [25] was considered to have dual objectives, with the first being to collect baseline data regarding the knowledge and perception of food and fibre production from multi-discipline teachers. These data were then used by Cosby, Manning and Trotter [25] to evaluate a PD programme (aim b, discussed below).

Aim b: Evaluate the Effectiveness of Teacher PD

Four studies aimed to evaluate the effectiveness of teacher PD to increase teacher knowledge and self-efficacy to integrate AgTech into the classroom. Hanley et al. [26] studied the effectiveness of PD developed for multidisciplinary teachers using geospatial technologies to increase teacher knowledge of this field and evaluate their ability to apply this knowledge into classroom lessons. Whannell and Tobias [27] evaluated PD for high school teachers to help develop an understanding of the role of maths, science and information technology in future farming to encourage the implementation of digital technologies in classrooms. Cosby, Trotter, Manning, Harreveld and Roberts [17] evaluated the 'GPS Cows module', a livestock tracking technology to determine teacher perceptions of appropriateness for secondary school students and to determine barriers and enabling factors for implementation. Finally, Cosby, Manning and Trotter [25] evaluated PD which included on-farm activities to increase the teachers' knowledge and understanding of the AgTech impact on the industry to provide context to their learning.

Aim c: Evaluate the Effectiveness of Classroom Activities

Three studies aimed to evaluate the student learning outcomes of classroom activities to increase the AgTech knowledge, attitude or capabilities of students. Two of these studies [28,29] also evaluated teacher perceptions of the activities. Mueller, Knobloch and Orvis [28] used the 'Apple Genomics Project' to evaluate active versus passive learning in biotechnology and genetics to determine the impact on high school student learning. The

teachers' perceptions of the experience, including overall unit impression, student engagement and if they would teach the unit again in the future, was also examined. Paulsen, Polush, Clark and Cruse [29] evaluated the student learning outcomes of a two-to-four-week soil conservation classroom curriculum, including relevant pre- and post-attitudinal perceptions and content knowledge of precision soil technologies. The content of the soil-based curriculum was developed by university agricultural educators in conjunction with secondary education teachers, and PD training was provided for teachers prior to classroom implementation [29]. Outside of the school-based classroom environment, Sami et al. [30] evaluated student learning outcomes of a two-week summer camp developed and run by university staff to use open-data for real world analytical projects. The summer camp targeted high school aged students recruited to the programme via an application process.

3.1.2. Study Methodologies

Several methodologies were employed in the reviewed studies. Seven studies used hard-copy or online surveys to collect data based on a single-point in time [18–24] (Figure 2a). Comparatively, three studies used both pre- and post-intervention surveys to gauge the change in knowledge and/or perceptions over time [25,29,30]. Two studies used methods of data collection after an intervention, such as PD, which had already occurred [17,27]. Another two studies utilised both pre- and post-intervention surveys and an additional post-intervention data collection method [26,28]. Post-intervention methods were the only studies to include data collection by methods other than surveys (n = 2), by focus group [17] or interview [26].

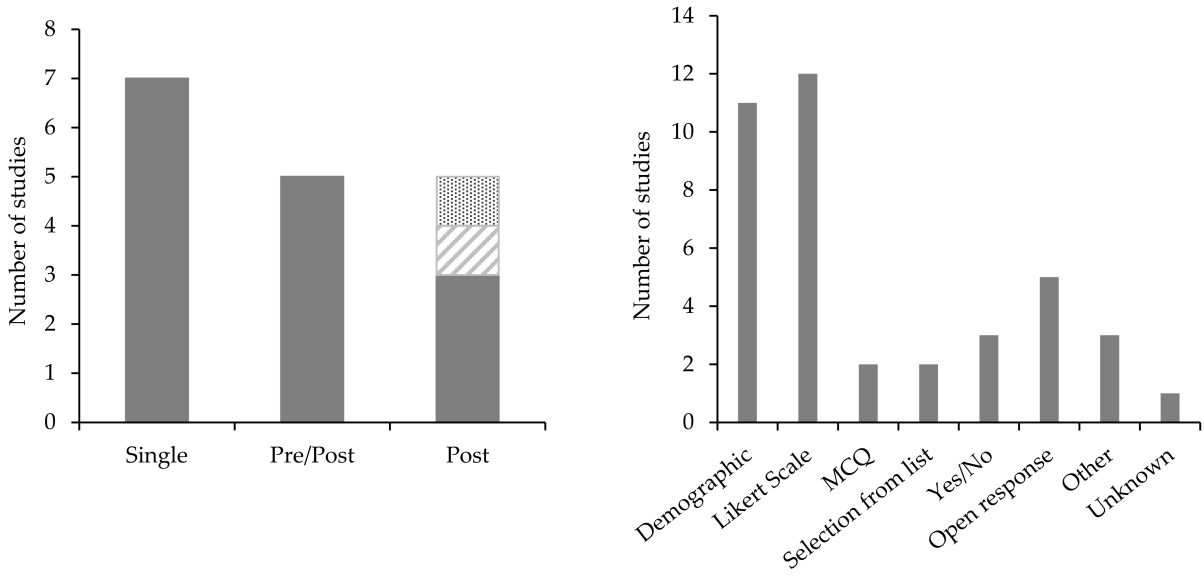

Figure 2. Summary of study methodologies: (**a**) time of data collection including a single point in time (Single), pre- and post-surveys (Pre/Post) or post-intervention (Post) and method of collection including survey (dark grey), focus group (diagonal stripe) or interview (dotted); (**b**) question styles utilised in surveys (MCQ: Multiple choice question. Other: Fill-in-the-blank, rating, true/false).

Of those studies that utilised surveys (n = 13), there was a relatively even distribution of online (n = 4) or paper delivery (n = 3). One study utilised both hard-copy and online forms [24]. The format of surveys for five studies was unknown [26–30]. The question styles utilised in the reviewed studies are shown in Figure 2b.

3.1.3. Participant Demographics

Most studies utilised teacher participants (n = 11) compared to student participants (n = 2), or both teacher and student participants (n = 1; Figure 3a). The distribution of participants per study is shown in Figure 3b (range: 8 [28] to 212 [24]). Of the 14 reviewed studies, the majority were conducted in the USA (n = 10). Three studies were conducted in Australia [17,25,27] and one was conducted in France [18]. The distribution of studies throughout the USA is shown in Figure 4.

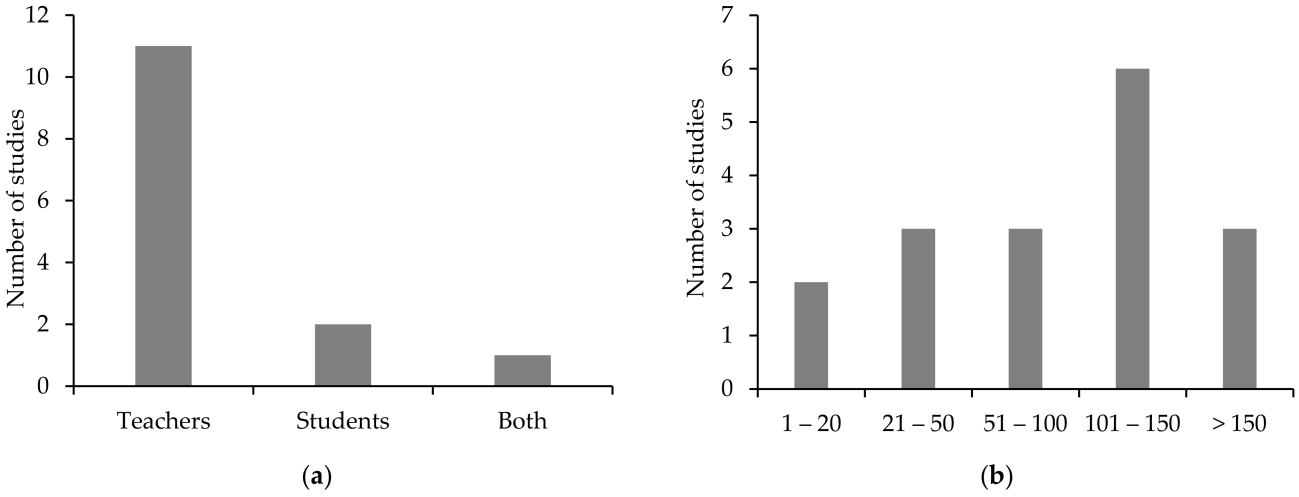

Figure 3. Summary of studies in terms of (**a**) participants and (**b**) sample size.

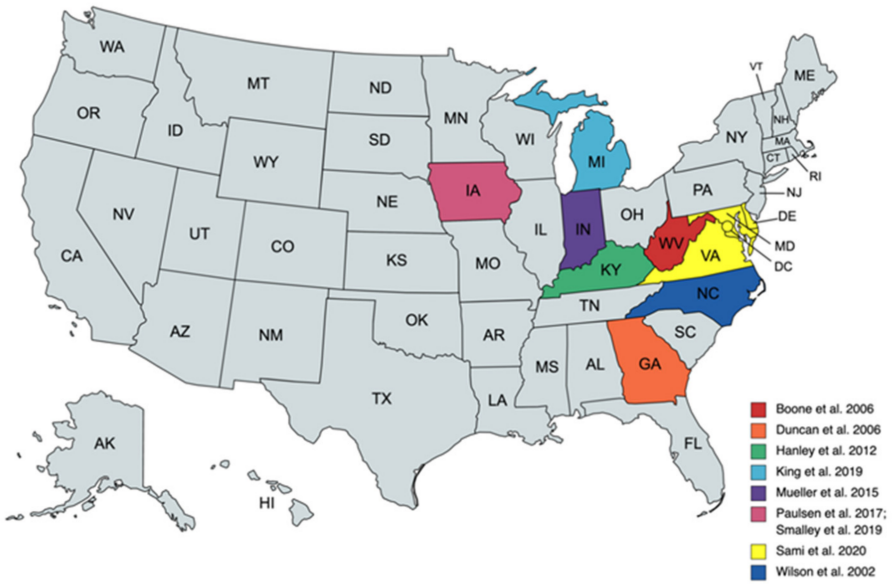

Figure 4. Distribution of study participants throughout the USA (n = 10). Additionally, Weeks, Lawver, Sorensen and Warnick [23] recruited participants across the nation (not shown). Map adapted from https://www.mapchart.net (accessed on 1 April 2022) licensed under Creative Commons 4.0.

3.2. RQ2: What Findings and Conclusions Were Produced?

3.2.1. Aim a: Determine or Increase Teacher Knowledge, Awareness or Attitude towards AgTech

Focusing on biotechnology as a subset of AgTech, Boone Jr, Gartin, Boone and Hughes [20] found teachers to have a positive attitude towards the topic, with 90% of teachers surveyed agreeing with the inclusion of biotechnology in the school curricula. However, teachers had limited knowledge on biotechnology and Boone Jr, Gartin, Boone

and Hughes [20] found no relationship between years of teaching and perceived biotechnology knowledge. A limited knowledge of biotechnology was also reported by Wilson, Kirby, Flowers and the American Agricultural Economics Association [19], with the majority of surveyed teachers accurately perceiving their lack of knowledge of this subject matter, while still recognising the benefits of curriculum inclusion. Regarding teacher attitudes toward biotechnology, Simonneaux [18] reported an overall agreement of multi-disciplinary teachers for the use of biotechnology in human medicine, in contrast to the application in agriculture where most disagreed. Additionally, Simonneaux [18] noted that those that taught humanities expressed a greater concern of biotechnology in comparison to science teachers.

In King, McKim, Raven and Pauley [21]'s study of the adoption of new and emerging AgTech in Michigan schools, teachers reported a relatively high perceived importance of the technologies (mean 3.58 out of 5), though the perceived competence was low (mean 2.54 out of 5). Despite this low competence, over half of the teachers reported teaching four of the fifteen technologies, including precision agriculture sensors, in the classroom. In addition, all but one of the fifteen technologies (digital twinning) was reported as being taught by at least one study participant. Most technologies were taught by lecture, the exception being unmanned aerial vehicles which was most commonly taught by lecture and demonstration [21]. In a similar study of teacher perception and knowledge of 21st century skills, Weeks, Lawver, Sorensen and Warnick [23] reported a relatively high perceived importance of these skills (mean 3.31 out of 5). Perceived knowledge scored similar (mean 2.99 out of 5), as did the perceived ability to teach the skills (mean 3.03 out of 5). Of particular interest for AgTech, technology literacy and information literacy consistently scored in the bottom third of skills, particularly technology literacy which scored 2.76 and 2.60 for perceived knowledge and perceived ability to teach, respectively [23].

Using a combination of teacher perceived importance and competence scores, Duncan, Ricketts, Peake and Uesseler [24] reported a calculated mean weighted discrepancy score as a way of determining the greatest "needs" of the surveyed teachers. Technical skills for the integration of current advances in agriculture technology into the curriculum was considered the highest "preparation need" of pre- and in-service agriculture teachers. Using the same analysis technique, Smalley, Hainline and Sands [22] reported a high need for the exploration of career opportunities in agriculture and the use of technology in teaching, as well as the integration of current advances of AgTech into the curriculum. Finally, Cosby, Manning and Trotter [25] also reported low levels of teacher knowledge of AgTech, with only 33% and 37% of surveyed teachers able to identify the potential for AgTech to improve farm animal welfare and environmental sustainability, respectively.

3.2.2. Aim b: Evaluate the Effectiveness of Teacher PD

Following the attendance of computer-based workshops that introduced teachers to digital resources relevant to middle year mathematics and science and senior year agriculture, Whannell and Tobias [27] found that 70% of teachers self-rated their ability to use computers and online resources as good to very good. This was particularly true for females who reported higher self-efficacy than their male counterparts. Though beneficial to show teacher ability to use digital resources for general teaching purposes, Whannell and Tobias [27] did not examine the teachers' ability to use digital AgTech resources more specifically. In comparison, Cosby, Trotter, Manning, Harreveld and Roberts [17] examined the use of digital resources for AgTech teaching by way of focus group discussions following the completion of the 'GPS Cows module' and workshop. This PD workshop was used to demonstrate and engage teachers in a practical class activity, designed to introduce students to GPS livestock tracking technology. Teacher skill development was perceived as one of the biggest barriers to implementation, including concerns regarding data manipulation and understanding the analysis techniques, and many requested that ongoing support would be beneficial. Nevertheless, teachers perceived that overall student engagement and enjoyment of the activity would be high.

In a similar study, Hanley, Davis and Davey [26] engaged teachers in two weeks of PD involving geospatial technologies, followed by applied learning in community projects over the following months. Based on the PD, teachers demonstrated an improvement in knowledge in 17 of 21 areas, including general Geographic Information System (GIS) skills (e.g., topology models), spatial data (e.g., vector data and storage formats), analysis (e.g., buffering) and database skills (e.g., queries, cardinality, joining external tables). Hands-on activities were rated as the most effective at improving knowledge. Despite intensive instruction, however, teacher self-rated readiness for the post-PD community activities was only 59% due to a perceived limited understanding of GPS technology. Following classroom application, the use of an "authentic science experience" and the direct connection of the technology to the students was considered positive by teachers. This was evident by the increased interest, confidence and knowledge of both students and teachers. The involvement of the school information technology (IT) staff was noted as an important success factor to overcome individual teacher limitations with technology, as was the opportunity to collaborate with other teachers to discuss what was or was not working in the classroom.

The 'TeacherFX' PD programme, described by Cosby, Manning and Trotter [25], was a two-day event, consisting of multiple farm visits and a professional learning activity involving AgTech, in addition to an overnight stay at a local farm. Cosby, Manning and Trotter [25] reported a need for more teacher PD, industry and teacher networking and online resources to support the increase of food and fibre content in teaching programmes. Prior to participation, 62% of participants stated that they incorporated food and fibre concepts into current teaching programmes and 82% wished to increase this content. Following PD completion, 92% of participants either agreed or strongly agreed that authentic data improve the students' learning experience, and 96% were likely to encourage students to consider future employment in the agricultural industry based on their improved perception of the modern agricultural industry and improved knowledge of AgTech innovations in use.

3.2.3. Aim c: Evaluate the Effectiveness of Classroom Activities

The incorporation of hands-on learning in addition to the use of the computer-based modules of the 'Apple Genomics Project' by Mueller, Knobloch and Orvis [28] found students achieved higher post-test knowledge application scores compared to those that were taught by a traditional lecture format, demonstrating a clearer understanding of the subject matter and critical thinking. However, teachers perceived a higher level of student engagement from the latter group, though the difference was not significant. In addition, many teachers found the material too advanced for their classrooms and would have benefited from more background information and learning materials. In a similar study, Paulsen, Polush, Clark and Cruse [29] evaluated student learning following a two-to-four-week soil conservation programme. Overall, students had a higher percentage of correct responses in a post-content test (mean 66.9%) compared to pre-content (mean 47.8%). An examination of knowledge for only those questions relevant to AgTech was also positive (mean 38.3% pre-content versus 60.1% post-content), except for understanding the advantages of LiDAR (a remote sensing AgTech) which remained low (36.2% correct responses for both pre- and post-content). The reason for this was unknown, however, the author's speculated it could have been due to misleading or ambiguous answer choices.

In an out-of-classroom study, Sami, Sinclair, Stein and Medsker [30] investigated the impact of a two-week summer camp on Microsoft Excel, Tableau (data visualisation software) and ESRI ArcGIS (spatial data software) skills, when applied to science, technology, engineering, agriculture and maths (STEAM) topics. By way of self-reported knowledge, the authors noted an improvement in knowledge and skills across all areas, including the above-mentioned software, data transformation, data storage, data collection and presentation skills. Though the self-reported improvement of students may not be indicative of actual improvements in applicable knowledge and skills for agricultural education benefits,

the camp was considered an overall success and showed that students were able to quickly gain confidence and adapt to the material.

3.3. RQ3: What Are the Barriers to Utilising Agricultural Technology in Secondary School Agricultural Education Programmes?

The main limitations to teaching AgTech in classrooms were found to be related to access to funds and resourcing for equipment and training, time and skill ability of the teachers. Limited funding in schools can impact teacher access to the required computer equipment and resources needed for AgTech lessons [17,19,25,27]. Smalley, Hainline and Sands [22] also noted the current reliance by teachers on agricultural organisations, universities and professional organisations for their PD and identified the need for teacher PD in all areas of AgTech, including teacher skill development. This is particularly important considering the low technology skills and limited AgTech knowledge of teachers identified in the reviewed studies [17,19–21,23,25]. Finally, a lack of time is also cited by teachers as a significant barrier for AgTech incorporation [17,25], including the time required to research and self-learn new technologies for curriculum implementation.

4. Discussion

The results of this systematic review show the growing emergence and utilisation of AgTech in secondary school agricultural education programmes across the globe. Major themes identified in the literature include the need for sufficient pre-service learning and continued support for teachers, including PD.

4.1. The Role of the Pre-Service Teaching Curriculum

To ensure the adequate preparation of pre-service teachers, the improvement of university agricultural teacher education is essential. Duncan, Ricketts, Peake and Uesseler [24] emphasised the need for university educators to include more current agriculture technologies in their pre-service teacher curricula. This was similar to Weeks, Lawver, Sorensen and Warnick [23], who noted that the inclusion of relevant technology skills in pre-service teaching education, with a focus on explicit ways to implement the skills in the classroom, would in turn improve student learning. The use of agricultural industry professionals and recruiters at pre-teacher seminars was also recommended by Duncan, Ricketts, Peake and Uesseler [24] as a method of improving teacher understanding of post-secondary education in food and fibre industries. Finally, Weeks, Lawver, Sorensen and Warnick [23] indicated that pre-service education should encourage critical thinking, a skill that can then be passed on to school students to improve their chance of employment following graduation.

According to Bastos et al. [31], tertiary educators must participate in a new role in the preparation of their students for entry into the workforce, including the way students use technology. An assessment of pre-teacher ICT skill progression by Gill et al. [32] reported the inconsistent development of technical skills for 11 students as they progressed through their university programme. For example, one participant showed the fastest and greatest progression of skill development, which was attributed to exposure to a range of casual teaching experiences. In comparison, another participant who received little guidance concerning the use of ICT during classroom placements, exhibited a slower skill progression. Gill, Dalgarno and Carlson [32] speculated that this was due to the inadequacy of the university course to supply the required skills for ICT application and reiterated the importance of being able to observe or use the required technologies for improved learning. Ozer et al. [33] affirmed the importance of ensuring teachers are aware of technologies before being taught how to integrate them into the curriculum, though again, stated that, parallel to tertiary learning, providing opportunities to use technologies as pedagogical tools in the classroom is also important.

Focusing on AgTech, it has been stated that tertiary educators need to change the way they educate students to prepare them for the challenges of the agricultural industry [34]. This was examined by Vickrey, Golick and Stains [34], who evaluated the use of technology

in tertiary agriculture pedagogy. Typical technologies reported for agriculture teaching included the delivery of module content with dynamic functionality (e.g., tools that allowed students to manipulate objects in space or time), collaborative tools such as technology-facilitated small group discussions or brainstorming activities, spatial analysis technologies (e.g., GIS software to learn field techniques) and modelling activities to explore more complex processes (e.g., phenotypic variation). Though not specific to AgEd teachers, the findings by Vickrey, Golick and Stains [34] provide insight into appropriate technologies that can be incorporated into school situations, particularly when we consider the increasing pressure on high school teachers to make sure students are workforce ready.

4.2. The Role of Professional Development

A major theme of the reviewed literature is the need for additional AgTech-specific PD for teachers. Recommendations by King, McKim, Raven and Pauley [21] included more PD with an emphasis on learning alternate methods of teaching AgTech content to allow for student application and depth of learning. This is supported by Mueller, Knobloch and Orvis [28], where students who engaged in active learning had more positive perceptions of their experience than those enrolled in passive learning environments (e.g., learning by lecture only). Providing teachers with guidance on how to incorporate AgTech into the curriculum was also recommended by Smalley, Hainline and Sands [22], as was ensuring the PD was correct for the audience, including the duration and the use of audience participation for engagement purposes. This second recommendation is similar to Paulsen, Polush, Clark and Cruse [29] and Whannell and Tobias [27], who affirm that PD should consider student and teacher background knowledge [29] and student literacy levels [27]. The provision of support materials to teachers [28] or scaffolding of lessons [17] is also recommended to aid in the effectiveness of AgTech teaching. Finally, AgEd PD should offer networking opportunities with other teachers and agricultural professionals [25], and ongoing guidance from the PD team [26] to support participants and encourage reflection.

In addition to specific AgTech skills and knowledge, general digital skills are also important for teachers, particularly as the need for workforce entrants capable of adapting to 21st century skills continues to rise [23]. To ensure teachers offer the most up-to-date learning environment for their students, they must be trained in the most up-to-date content and technologies [29]. This can be achieved through adequate PD and in-service teacher training, including the provision of varied opportunities dependent on the teachers' level of skill and expertise [22,35]. In addition, Hanley, Davis and Davey [26] recommend the use of IT staff to assist in the set up and use of AgTech in the classroom.

Similar to the recommendation by Duncan, Ricketts, Peake and Uesseler [24] to include agricultural industry representatives in pre-service teaching seminars, stakeholder involvement in the design and development of teacher PD was also recommended by King, McKim, Raven and Pauley [21] as a method of ensuring industry relevance. The use of the collaborative development of learning resources was also endorsed by Sami, Sinclair, Stein and Medsker [30], stating that the inclusion of different stakeholders such as university and industry professionals and software experts was valuable during lesson development as it ensured the latest tools and methods were used and authentic examples were presented. Finally, Smalley, Hainline and Sands [22] support the use of various PD entities, including university personnel and specialised PD providers (e.g., Iowa Association of Agricultural Educators), to ensure varied and industry-specific PD delivery.

4.3. The Cost of Agriculture Technology Education

To support student learning of AgTech in schools, sufficient basic (e.g., computers, software, etc.) and advanced (e.g., sensors, remote sensing, etc.) technology resources are required. Although schools around the globe are, in general, becoming increasingly equipped with hardware [36], limited access to technology is still reported as a barrier for teaching, particularly in rural schools [25,27]. In addition, broadband internet availability is often inadequate in rural and regional areas [37,38] and competing school priorities in

schools may limit school funding for resources [39]. AgTech can be costly for schools to not only implement, but maintain, such as ongoing software subscriptions or repairs to equipment, and therefore, additional future funding may be necessary [25]. This includes support through external funding schemes from industry or educational organisations, the use of free education software subscriptions or trials, or the collaboration with schools in an area to share costs [40]. This would allow not only access to technology, but also improve access to field trip activities or hands-on learning that provide deeper learning opportunities for students than standard lecture-based teaching [21,26].

4.4. Recommendations for Future Research

Future research was recommended to evaluate the extent of student learning and skill development from the classroom activities rather than a focus on student engagement [21,30]. Additionally, new ways to increase the agricultural literacy of primary and secondary students worldwide is needed [41]. This should expand to include a broader understanding of IT and digital skill development, which is generally considered to have been given a strong emphasis in modern classrooms. However, unless teachers are digitally literate, the incorporation of AgTech into the curriculum and teaching programmes will remain unchanged [25]. The methods of evaluating the skill level of teachers to engage with the technologies should move beyond evaluating teacher self-efficacy and self-rated technology ability to challenge-based testing as their self-rated ability may be overestimated and be insufficient to meet the requirements in the classroom. This should include more research into the methods used to teach the skills in the classroom [23], for example, animations (non-interactive but dynamic content), modelling technology (mathematical representation of content) or collaborative tools (technology that facilitates student–student interactions) [34]. In addition, future research should explore the relationship between exposure to technology through PD and the subsequent incorporation into the curriculum, including the effectiveness of this incorporation [17,21]. This highlights the opportunity to engage a range of stakeholders to change the utilisation of AgTech in secondary school agricultural education programmes across the globe, such as the involvement of education departments [17] or industry [25].

5. Conclusions

The results of this systematic review show the utilisation of AgTech in secondary school agricultural education programmes across the globe is limited. As the world's population continues to grow, the need for global food security and environmental sustainability has never been higher. The incorporation of AgTech can help to address this, though the ability to convert the use of AgTech into actionable knowledge relies on the knowledge and skills of the user [9]. To support new workforce entrants, including adequate skill development and knowledge of career opportunities, the introduction of AgTech into the school setting is important. As shown throughout this review, several studies have been published that examine the use of AgTech in secondary school classrooms and provide insight into the requirements for PD and classroom activities, as well as barriers to curriculum implementation. Key areas to address AgEd teacher knowledge development include improvements of the pre-service teaching curriculum at tertiary providers and the use of in-service PD to maintain and improve teacher knowledge. For the former, pre-service teachers should be exposed to the technologies and be provided with opportunities to implement the technologies in the classroom. The use of technology to improve agriculture student learning at university can also be used to model student knowledge development in school classrooms. PD should be used to improve or maintain teacher knowledge of AgTech and should provide teachers with guidance on how to incorporate AgTech into the curriculum. The provision of classroom materials or lesson scaffolding is also recommended. Collaborative development and delivery of PD can help to ensure the programmes remain industry relevant. In addition, the use of authentic data is highly recommended. Finally, barriers for AgTech incorporation into schools, including adequate

funding and access to technologies are critical to ensure student learning and skill development, particularly in rural schools where infrastructure and physical access to technologies may be limited.

The application of the findings of this review could be used by teachers and schools to improve current PD and the use of AgTech in the curriculum, including countries where reviewed studies on AgTech with secondary school students and/or teachers are limited. Industry organisations, universities and policymakers can also use these findings to design pre-service teacher programmes, in-service PD and school programmes that increase their knowledge and skills in AgTech and the agriculture sector more broadly. This will, in turn, increase the quality of new workforce entrants into agriculture, improving productivity, profitability, animal welfare outcomes and industry sustainability.

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Abbreviations

Ag: Agriculture; AgEd: Agriculture Education; AgTech: Agricultural Technologies; BNAM: Borich Needs Assessment Model [42]; MCQ: Multiple-Choice Questions; MWDS: Mean Weighted Discrepancy Score; PD: Professional development.

Appendix A

Table A1. Analytic matrix of results.

Reference, Location	Aim [1]	Detailed Aim	General Method/s	Sample Size and Participants	Findings	Recommendations
Boone Jr, Gartin, Boone and Hughes [20], USA	a	Determine teacher knowledge and attitudes to biotechnology.	Single survey (paper-based) **Details:** Likert-scale questions to gauge knowledge and attitudes of biotechnology	N = 62 high school AgEd teachers	90% agreed biotechnology should be included in AgEd Overall limited knowledge on biotechnology topics	Biotechnology should be included in curriculum Funding required for training and resources to support inclusion Support for teachers with PD and changes to pre-service teacher training to ensure sufficient topic knowledge
Cosby, Trotter, Manning, Harreveld and Roberts [17], Australia	b	Evaluate university-developed learning resources—teacher PD.	Post-intervention focus groups **Intervention:** Lectures and practical sessions on livestock GPS tracking	N = 10 high school AgEd teachers	Teacher self-identified barriers: low technical skills and access to class computers High teacher willingness to engage with content to ensure their teaching programme is industry relevant Perceived student engagement with learning resources would be high	Teachers need ongoing support of the PD team with resources and scaffolding of lessons

Table A1. *Cont.*

Reference, Location	Aim [1]	Detailed Aim	General Method/s	Sample Size and Participants	Findings	Recommendations
Cosby, Manning and Trotter [25], Australia	a, b	Increase awareness of Ag industry and teacher understanding of, and barriers to, Ag technology use.	Pre- and Post-intervention survey (Online) **Intervention:** Two-day PD including overnight on-farm showcasing technologies including livestock tracking	N = 27 teachers (K-12), multiple disciplines	62% of teachers incorporate food and fibre content Post-intervention: 82% wished to increase food and fibre content Programme successful at increasing engagement between farmers, teachers and industry professionals Knowledge and industry perception improvement post-intervention	Need to overcome teacher barriers to increase food and fibre lesson content Teachers require more PD, online resources, industry networking, internet and computer resources and funding for equipment
Duncan, Ricketts, Peake and Uesseler [24], USA	a	Determine AgEd teacher in-service needs including technology.	Single survey (Paper-based and online) **Details:** BNAM; Likert questions regarding competency and perceived importance; MWDS calculated	N = 212 middle and high school AgEd teachers	Limited findings specifically related to technology Teachers have high perceived need to learn methods of motivating students to learn	Pre-service teaching curriculum modifications to include current advances in agriculture and how to integrate technology into curriculum Industry professionals to attend teacher seminars and PD to improve teacher understanding of student pathways post-secondary
Hanley, Davis and Davey [26], USA	b	Conduct and evaluate university-developed teacher PD of geospatial technologies and classroom application.	Pre- and post-intervention survey (unknown format) Additional post-intervention survey (unknown format) and interview **Intervention:** Two-week PD followed by school community projects (12 months)	N = 105 middle and high school teachers, multiple disciplines (mainly science)	Improvement in teacher knowledge in 17/21 areas following PD, although knowledge of GPS still low Hands-on activities highly rated Teacher readiness for community projects rated 5.9/10 following PD Students engaged and motivated by activities	Ongoing support by PD team required Financial support for field trips and classroom equipment required Involvement of school IT personnel recommended to overcome teacher limitations with technology
King, McKim, Raven and Pauley [21], USA	a	Explore current needs and adoption of 15 new and emerging agricultural technologies within the curriculum to determine teacher PD needs	Single survey (online) **Details**: Needs assessment using Likert questions; MWDS calculated; other questions regarding current engagement, teaching methods and student engagement	N = 47 high school AgEd teachers	Rated importance of AgTech inclusion in curriculum higher than their competence to teach Student engagement high Lectures were the most common teaching method	Curricular review to include AgTech to prepare future learnersFuture studies to review impacts on student learning, not only student engagement Stakeholder involvement in teacher PD, including demonstration of teaching methods other than lectures

Table A1. *Cont.*

Reference, Location	Aim [1]	Detailed Aim	General Method/s	Sample Size and Participants	Findings	Recommendations
Mueller, Knobloch and Orvis [28], USA	c	Evaluate student knowledge outcomes' passive versus active learning groups using Apple Genomics genetics and biotechnology focused programme.	Pre- and Post-intervention survey of student knowledge (unknown format) Post-intervention survey of teacher perceptions (unknown format) **Intervention:** two parallel teachings: passive learning (lecture only) and active learning (computer modules and lab activities).	N = 8 teachers, 200 high school students	Post-test student knowledge scores not significantly higher in active learning group Active learning group demonstrated higher knowledge application and critical thinking Teachers perceived content too advanced and required support and background materials and learning	Programme should provide support materials to teachers for student pre-learning
Paulsen, Polush, Clark and Cruse [29], USA	c	To test the impact of university-developed precision soil and water conservation curriculum on student knowledge and attitude.	Pre- and Post-intervention survey (unknown format) **Intervention:** 2–4-week precision soil conservation curriculum. Surveys used to determine attitudes and knowledge	N = 52 high school students	Teachers needed more training prior to implementation Limitation: only one lesson dedicated to AgTech (LiDAR)	Teacher training to include methods to adapt content to cater for background knowledge and abilities of students
Sami, Sinclair, Stein and Medsker [30], USA	c	Determine knowledge and skill improvement following 2-week university-led agricultural data analytics summer camp	Pre- and Post-intervention survey (unknown format) **Intervention:** two-week summer camp using real-world data	N = 25 students, mean age 16 years	Demonstrated Excel knowledge and skill improvement 92% of students enjoyed the camp Limitation: self-report did not provide definitive proof of learning and skill development	Skill challenge testing to determine actual rather than perceived skill improvement External industry stakeholder involvement was valued in the course design and activities
Simonneaux [18], France	a	To determine whether teacher traits influence knowledge and opinion on biotechnology topics.	Single survey (paper-based) **Details:** level of agreeance with various statements regarding biotechnology	N = 105 teachers, multiple disciplines	Overall agree with use of biotechnology in human medicine and raw material production Limitation: focused on attitudes towards technology and not on use of technology	Limited
Smalley, Hainline and Sands [22], USA	a	Determine PD needs of AgEd teachers in areas including technical agriculture.	Single survey (online) **Details:** BNAM; Likert questions regarding competence and perceived importance; MWDS calculated. 13/20 items assessment regarding AgTech	N = 147 AgEd teachers	Need for teacher PD for all items in technical agriculture category Highest perceived need in teaching biotechnology, agribusiness and integrating advances in AgTech into the curriculum Current reliance on Ag teaching organisations, university and industry professionals for PD	More teacher PD across multiple areas, with curriculum integration support

Table A1. *Cont.*

Reference, Location	Aim [1]	Detailed Aim	General Method/s	Sample Size and Participants	Findings	Recommendations
Weeks, Lawver, Sorensen and Warnick [23], USA	a	Examined AgEd teachers' perceptions and knowledge of 21st century skills agriculture skills to help determine PD needs.	Single survey (online) **Details:** BNAM; Likert questions regarding competence and perceived importance and ability to teach; MWDS calculated	N = 98 AgEd teachers	Majority perceived 21st century skills important Self-rated technical literacy knowledge as somewhat knowledgeable Self-rated ability to teach 21st century technical skills as somewhat competent Lacked knowledge to teach specific skills	Further research into how the AgTech skills are being taught in schools and teacher self-efficacy More teacher PD focused on emerging technologies
Whannell and Tobias [27], Australia	b	Teacher PD workshops to understand role of maths, science and IT in future farming to encourage teacher promotion of industry to students.	Post-intervention survey (unknown format) **Intervention:** four-day workshop using online resources	N = 195 science and AgEd teachers	70% self-rated ability to use computers Females significantly higher computer self-efficacy, attitude and intention to use digital classroom Teachers identified potential challenges being computer access in rural schools and engagement of students with lower literacy	PD should consider targeting student literacy levels Limited access to technology is a barrier for teaching, particularly in rural schools
Wilson, Kirby, Flowers and American Agricultural Economics Association [19], USA	a	Determine teacher intent to adopt specifically designed biotechnology curriculum and determine teacher knowledge and barriers to adoption.	Single survey (paper-based) **Details:** Likert questions regarding perceived knowledge, importance, intention to adopt and barriers for adoption; MCQ of actual knowledge	N = 126 high school AgEd teachers	Teachers perceived inclusion of biotechnology curriculum as important, with self-perceived knowledge being 'somewhat knowledgeable' Teachers with fewer years of experience and past biotechnology training were more likely to show willingness to adopt the curriculum Actual knowledge score: mean 69% Almost half of teachers not meeting the expected passing score of assessment designed for students Identified barriers to adoption of biotechnology curriculum being lack of equipment, funding, low teacher knowledge	Future studies should compare the knowledge of teachers in competency areas against the value they place on those competencies Areas of lowest competency to be determined for future training Pre-service teaching courses to address shortfall in knowledge

[1] Aims: (a) to determine or increase teacher attitude toward, knowledge or awareness of AgTech; (b) to evaluate the effectiveness of teacher PD; or (c) to evaluate the effectiveness of classroom activities to increase AgTech knowledge, attitude or capabilities of students.

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