education sciences

MDPI

Article

Teaching Innovation in STEM Education Using an Unmanned Aerial Vehicle (UAV)

Madeleine M. Bolick *, Elena A. Mikhailova and Christopher J. Post

Department of Forestry and Environmental Conservation, Clemson University, Clemson, SC 29634, USA; eleanam@clemson.edu (E.A.M.); cpost@clemson.edu (C.J.P.)
* Correspondence: madelei@g.clemson.edu

Abstract: The use of unmanned aerial vehicles (UAVs) has increased in the science, technology, engineering, and mathematics (STEM) professions. This means there is a growing need to integrate UAV training into STEM education. This study aimed to develop and evaluate a UAV education module and laboratory exercise for natural resource science students. The study used a series of reusable learning objects (RLOs) to assess students' prior knowledge of remote sensing and UAVs. Students were taught the steps of UAV data acquisition and processing through lectures and UAV simulation videos. Students applied this knowledge by completing a laboratory exercise that used previously collected UAV data. Student knowledge retention and understanding were evaluated using an online quiz to determine the effectiveness of the education module. The average quiz score was 92%, indicating that the UAV laboratory exercise effectively taught students about UAV data acquisition and processing for natural resource research. Overall, students expressed positive opinions about the UAV education module. Student feedback indicated that the laboratory exercise was engaging, but some students would have preferred a hands-on experience for some parts of the exercise. However, in-person UAV instruction may not be accessible for all educators because of UAV cost or lack of instructor training. This study provides educators with crucial recommendations for designing UAV exercises to improve access to UAV-related educational content. This study indicates that online training can effectively introduce students to UAVs. Given the wide range of UAV uses across STEM fields, students in many STEM disciplines would benefit from UAV education.

Keywords: drones; e-learning; geographic information systems (GIS); reusable learning object (RLO); remote sensing

check for updates

Citation: Bolick, M.M.; Mikhailova, E.A.; Post, C.J. Teaching Innovation in STEM Education Using an Unmanned Aerial Vehicle (UAV). *Educ. Sci.* **2022**, *12*, 224. https://doi.org/10.3390/educsci12030224

Academic Editors: Pao-Nan Chou and Kuen-Yi Lin

Received: 8 February 2022
Accepted: 14 March 2022
Published: 18 March 2022

1. Introduction

1.1. Benefits of Using UAVs in Education

Unmanned aerial vehicles (UAVs), commonly known as drones, are defined as aircraft that are operated without an onboard pilot [1]. Early UAV applications focused on data acquisition and reconnaissance for military intelligence, or they were used in missions too risky for human-crewed aircraft [2]. As technology has advanced, the cost of UAVs has decreased, expanding UAV use into recreation and research over the past two decades [3]. More recently, UAVs have been widely used for data collection across various careers and research areas, driving a need to incorporate UAVs into education.

The widespread use of UAVs as research tools for gathering high-resolution imagery has led to a call for increased integration of UAVs into education [4,5]. A study of new and emerging technologies in natural resource education found the need for UAV instruction to be second highest, after blockchain technology [6]. Al-Tahir et al. [4] suggest three different methods to introduce UAVs into education: have students conduct a capstone project with UAVs, incorporate a UAV education module into an existing course, or create an entire course on UAVs. Alkaabi et al. [7] found that a hands-on UAV workshop for students at the United Arab Emirates University improved the student's teamwork, communication, and critical-thinking skills. The study also found that the UAV workshop taught students real-world problem-solving skills [7]. Overall, UAV education can be applied to numerous STEM disciplines and teach students valuable skills (Figure 1).

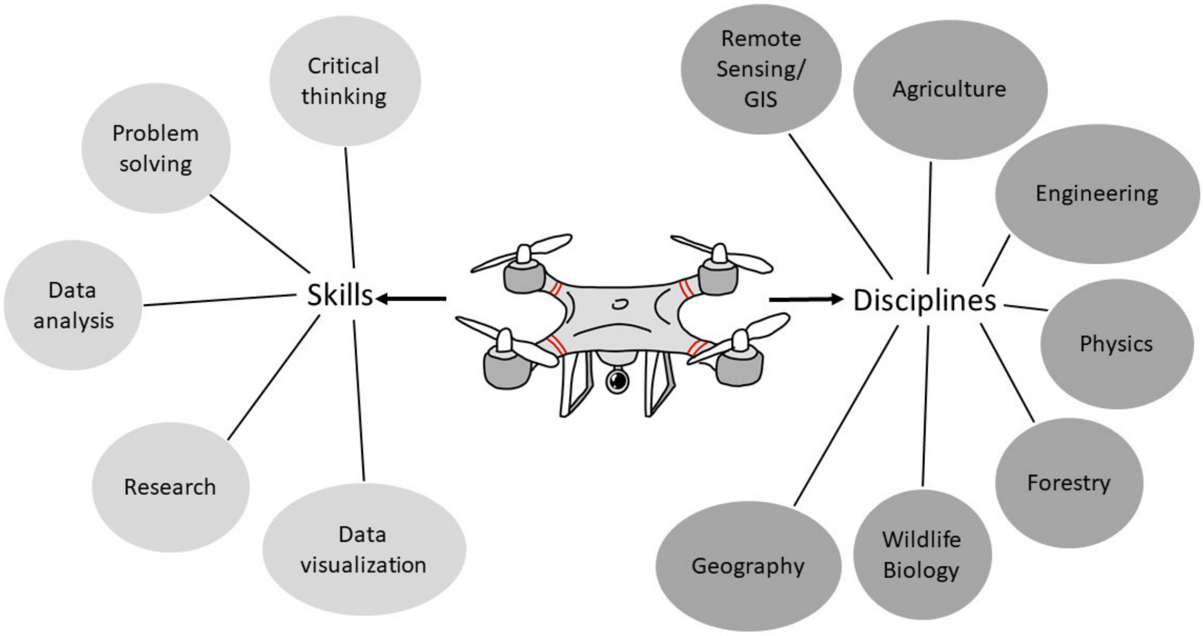


Figure 1. Examples of UAV skills that can enrich various educational disciplines.

Despite the high perceived need to incorporate UAVs into natural resource education [5,6], several barriers have prevented widespread UAV training. A recent study in Michigan found that only 37% of 131 surveyed secondary agriculture, food, and natural resources teachers had incorporated UAVs into their curriculum [6]. This was attributed to a lack of subject familiarity or access to technology because of funding constraints [6]. Regulations for UAVs restrict who can legally fly a UAV and the flight location. For example, in the United States, the Federal Aviation Administration (FAA) requires all UAVs over 0.55 pounds to be registered, and the UAVs must be flown at or below 400 feet within sight of the pilot [1]. While educational flights are exempt from additional restrictions under rule 14 of the Code of Federal Regulations (CFR) Part 107, all students must complete an aeronautical knowledge and safety course and pass The Recreational UAS Safety Test (TRUST) [1], which is available online at no cost. In most use cases outside of recreational and educational use, an operator must be a certified remote pilot under the Part 107 regulations [1] in the United States. To pass the remote pilot certification, the operator must pass an exam covering UAV regulations, airspace classifications and regulations, weather effects on UAV operation, airport operations, radio communications, emergency procedures, and UAV maintenance [1]. Other countries, such as the United Kingdom, have similar regulations restricting UAV usage for students, impeding UAV usage in education [8]. Cliffe et al. [8] found that insurance requirements and safety concerns are significant barriers to educational UAV use. Privacy and safety concerns associated with UAVs also prevent UAV training [9]. Finn and Wright [9] surveyed European UAV industry representatives, data protection authorities, civil society organizations, and civil authorities and found these groups are concerned about UAV ethical issues like discriminatory use of UAVs, dehumanization of people surveilled by UAVs, and UAV missions that expand beyond the original mission's intent. These regulations and licensing requirements could impede the incorporation of hands-on UAV exercises for many educators.

1.2. Applications of UAVs in Various Fields

One of the most common functions of a UAV is capturing true-color photos of an area of interest. This function is widely applicable in STEM education. Since UAVs fly at low elevations, they can capture imagery with high resolution [10]. While aerial imagery products from remote sensing satellites, such as Landsat, have a pixel size of 30 m, UAV aerial imagery commonly has a pixel size of a few centimeters [11]. Advanced UAV platforms can include other sensors such as LiDAR, thermal sensors, and hyperspectral sensors. [10]. Another advantage of UAV imagery is that it can be updated more quickly than satellite or aerial imagery [12]. Therefore, educational UAV opportunities can be designed to examine a variety of environments and landscapes, making UAVs flexible teaching tools.

The versatility of UAVs also means they can be applied to numerous educational topics and tailored to fit the research goals of the educator and students. A UAV can be mounted with various sensors to study diverse disciplines. For example, remote sensing research commonly uses UAVs for vegetation monitoring. They are valuable crop and forest management tools because they replace time-intensive field sampling measurements. In agricultural research, UAVs have recently been used to accurately measure the heights of crops such as corn and sorghum [11,13]. Images collected by UAVs can be analyzed to assess crop health and growth trends [11,13]. Thermal and multi-spectral sensor-equipped UAVs enable researchers to quantify water stress in crops and orchards [12,14]. Measuring the biomass of grasslands, fields, and pastures with UAVs is a more affordable and flexible method than traditional ground sampling [15]. Likewise, UAV analysis can measure tree heights and tree growth over a season [16,17]. Data from UAVs can determine forest stand canopy cover density and produce accurate forest type models that describe tree age, height, and diameter at breast height [18]. Imagery from UAVs can be analyzed to classify riparian vegetation and identify tree mortality areas [19]. Additionally, UAVs can monitor fine-scale seasonal Arctic tundra vegetation changes [20]. These are only a few of the many fields of study that utilize UAVs, and these topics can serve as a starting point for educators creating educational content for students.

There are many UAV applications outside of vegetation monitoring that could serve as the basis for specialized UAV training. Soil erosion can be estimated with UAVs because of the high resolution of the photos [21–23]. Frakenberget et al. [21] used UAV imagery to examine agriculture soil surface gullies after rainfall, while d'Oleire-Oltmannus et al. [22] used UAV imagery to quantify gully erosion by creating 3D digital terrain models. The use of UAVs in the Arctic for climate change monitoring enables researchers to study quickly changing morphological features in glacial areas such as the Austre Lovén glacier in Svalbard [24]. Wildlife UAV-based analysis has included monitoring nesting bird colonies [25], tracking hammerhead sharks [26], and detecting the presence of mammalian species such as orangutans, elephants, and tigers [27]. Given the breadth of UAV uses in STEM, educators can select the most relevant topic for their students and design an accompanying UAV exercise.

Another advantage of UAVs is that the photos can be converted into 3D models, helping students visualize an area of interest. These 3D models are created through automated photogrammetry, which reconstructs the area from overlapping UAV images using software programs such as ERDAS-LPS, Agisoft Metashape, Pix4UAV, and Photomodeler Scanner [28]. A digital surface model (DSM) is an example of a 3D model that illustrates the top surface of all objects on the ground, including the heights of trees and buildings [29]. These DSMs provide crucial information about vegetation, including crop or tree volume [29]. These 3D models can then be used for many different types of analysis, such as flood evaluation and modeling. Gebrehiwot et al. [30] used UAV imagery to create a 3D point cloud to determine flood inundation depth. Quickly constructing 3D models is helpful after natural disasters to perform damage assessment [30]. Unlike researchers, students may not be able to travel to these places to collect data. Yet, they can still learn about data acquisition and processing through well-designed UAV exercises.

Recent studies have explored integrating UAVs into education curricula, but many focus on training students to fly and control UAVs [31,32]. For most UAV-based analyses, flight and data acquisition are automatic processes based on a pre-planned flight, so teaching UAV flight skills is unnecessary in most cases. For UAV education to apply to students' future careers, students must learn how to acquire data, process it, and use it for analysis. He et al. [33] designed a virtual interactive UAV exercise to teach students how to capture UAV data and process it into a 3D model recreation of an open-pit mine. However, the study did not assess the efficacy of the UAV exercise in teaching students about UAVs. This research study was conducted to develop and evaluate the effectiveness of a virtual UAV education module that does not require access to a UAV. This study hypothesizes that this education module will teach students about UAV data collection and processing and prepare them for real-world UAV applications. The objectives of the study were to (1) develop a virtual UAV education module to teach students the method of flying a UAV and processing the collected aerial images in a laboratory exercise, (2) evaluate if the module and laboratory exercise were effective means for teaching natural resource students about the role of UAVs in research, and (3) provide recommendations to educators for designing UAV educational content.

2. Materials and Methods

2.1. Background of the Course

The course, Geographic Information Systems for Natural Resources (FOR 4340/6340), is a three-credit course in the Department of Forestry and Environmental Conservation at Clemson University, Clemson, SC. FOR 4340 "develops competence in geographic information systems (GIS) technology and its application to various spatial analysis problems in natural resources. Topics include data development and management, spatial analysis techniques, critical review of GIS applications, needs analysis, and institutional context. GIS hardware and software, hands-on application" [34]. The course can also be taken at the graduate level (FOR 6340). GIS for Natural Resources is required for forestry, wildlife, and environmental science majors [34]. The students in the course were mainly forestry, environmental science, and wildlife biology majors, and the majority were seniors, with a few juniors and graduate students (Table 1).

Table 1. General information about the students who participated in the study (n = 52).

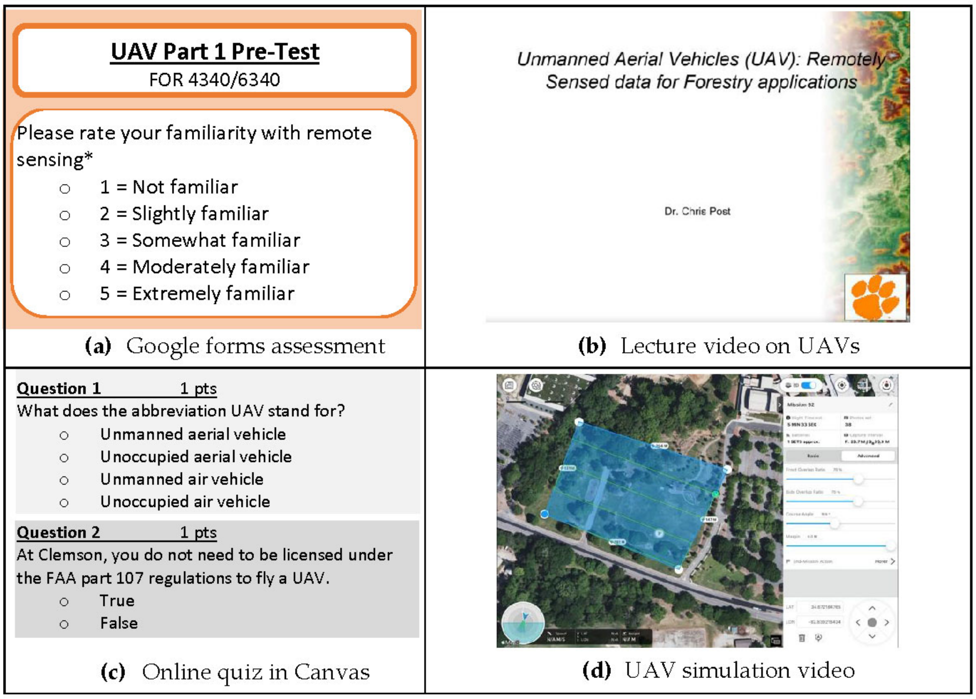
Survey Questions	Responses			
What is your major?	FOR (11)	ENR (14)	WFB (21)	Other (6)
What is your academic classification (year)?	Sophomore (0)	Junior (2)	Senior (45)	Graduate (5)
How would you describe yourself?	Female (25)	Male (27)		

Note: FOR = Forestry, ENR = Environmental and Natural Resources, WFB = Wildlife and Fisheries Biology.

2.2. Experimental Design

The UAV simulation consisted of a sequence of reusable learning objects (RLO). RLOs are defined by Valderrama et al. [35] as "any digital resource that can be reused to support web-based learning." Documents, webpages, live or prerecorded video or audio, or other pieces of content that are accessed independently and can be combined to create an instructional lesson can be part of an RLO [35].

The RLOs in this study (Figure 2) included: (1) a pre-assessment online survey in Google Forms, (2) a video lecture on UAVs in natural resource research and a series of UAV flight videos, (3) a laboratory exercise document with a video explanation that uses ArcGIS Pro [36] and Agisoft Metashape [37] software, (4) a graded online quiz on Canvas, and (5) a post-assessment online survey in Google Forms (Table 2).



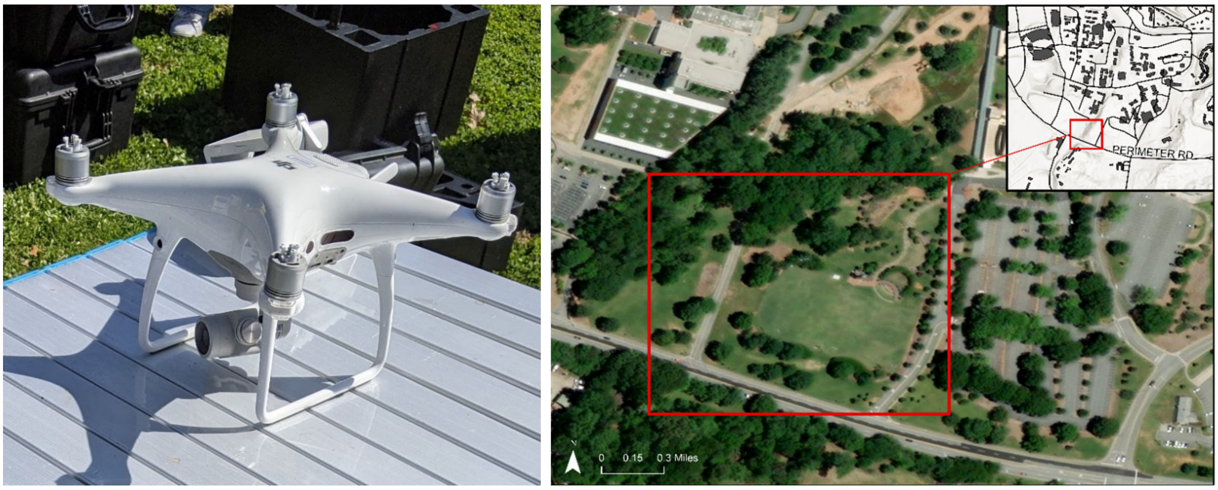
(a) Google forms assessment **(b)** Lecture video on UAVs **(c)** Online quiz in Canvas **(d)** UAV simulation video

Figure 2. Reusable learning objects (RLOs) for the UAV exercise: (**a**) Google Forms are used for pre- and post-assessment. (**b**) Students watched a recorded video lecture on UAVs in natural resource research. (**c**) A 10-question online quiz in Canvas tested the students' retention of module material. (**d**) A series of five videos demonstrated the steps required when flying a UAV to collect aerial imagery. The module website can be accessed at https://sites.google.com/view/for-43406340-drone-module/home (accessed on 14 March 2022).

Table 2. Reusable learning objects (RLOs) were used in the study to teach FOR 4340/6340 students about UAVs.

Steps	Activity Description
Part 1: Pre-assessment	Students answer an online survey via Google Forms about their familiarity with remote sensing and UAVs.
Part 2: Lecture + UAV Simulation Videos	Students watch a video lecture on UAVs and a series of five short videos illustrating the necessary steps to fly a UAV.
Part 3: Laboratory Exercise	Students complete the laboratory exercise in which they download images captured by the UAV and use Agisoft Metashape to process them into an orthophoto mosaic and digital surface model. They then use the DSM to calculate the height of trees and other points of interest in the study area.
Part 4: Graded Online Quiz	Students take a 10-question, 10-point online graded quiz in Canvas.
Part 5: Post-assessment	Students answer an online follow-up survey via Google Forms on their experience with the laboratory exercise and education module.

The series of UAV flight simulation videos included UAV set-up and pre-flight assessment, establishing the UAV flight path using the UAV's tablet application, UAV launch, UAV data collection, and UAV landing. Each video included photos, video footage, and voice-over audio. The videos were uploaded to YouTube and linked to a main Google site page for the students to watch. This exercise used the DJI Phantom 4 Pro UAV, which captured images of a field and urban forest on Clemson University's campus (Figure 3).



(**a**) (**b**)

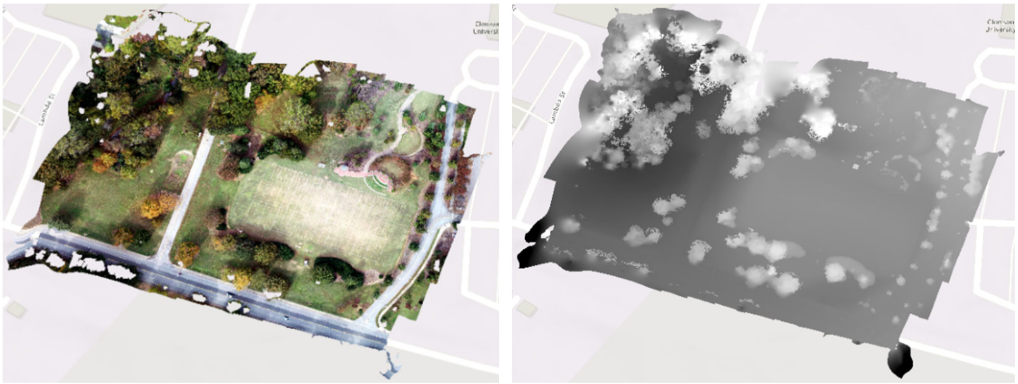
Figure 3. Collection device and location of the study area: (**a**) DJI Phantom 4 Pro UAV was used to collect study area images and create the module simulation videos and (**b**) Tiger Band Plaza study area on Clemson University's campus, Clemson SC, USA.

In the laboratory exercise (Figure 4), students were provided with 43 photos taken by the DJI Phantom 4 Pro UAV on Clemson University's campus. Students then used the Agisoft Metashape software package [37] to create an orthophoto mosaic and a digital surface model (DSM) from the UAV photos (Figure 5). An orthophoto mosaic combines multiple images into a single image with a uniform scale. The DSM depicts what is visible in the orthophoto, including ground, trees, and the tops of buildings. Students examined the orthophoto mosaic image in ArcGIS Pro [36] and were instructed to zoom in to observe the image's high resolution. Finally, students were provided with points of interest in the study area, including a tower and several trees. Students used the DSM to measure the heights of the points of interest by finding the elevation value of the ground next to the point and subtracting it from the point's elevation.

UAV Laboratory Exercise Summary

1. Students download a folder with 43 images captured by the UAV, along with a shapefile of points indicating several trees and a tower in the study area.
2. Students use Agisoft Metashape software to create an orthophoto mosaic image from the UAV images and a digital surface model (DSM).
3. Students export the orthophoto mosaic and DSM and open them in ArcPro to visualize the results.
4. Students measure the heights of the trees and tower, indicated by the points of interest shapefile, by finding the elevation value of the ground next to the point from the DSM, and subtracting it from the point's elevation, to get the total height of the tree or tower.
5. Students create a final map of the DSM and include the heights of the trees and tower they measured in the study area.

Figure 4. Summary of the laboratory exercise directions for FOR 4340/6340. Full instructions can be found in Supplementary Materials.



(**a**) (**b**)

Figure 5. Example outputs from the laboratory exercise created in Agisoft Metashape from 43 photos captured by the DJI Phantom 4 Pro UAV: (**a**) orthophoto mosaic and (**b**) digital surface model of Tiger Band Plaza at Clemson University.

In this study, students used Agisoft Metashape software to process UAV images because Clemson University had educational licenses available for student use. Processing the UAV images required internet access and specific computer resources (Table 3).

Table 3. Equipment and software requirements for running Agisoft Metashape in the laboratory exercise to process the UAV imagery and create an orthophoto mosaic and digital surface model (DSM).

Equipment	Requirements
CPU (central processing unit)	4–8 core Intel, 2.0+ GHz
GPU (graphics processing unit)	NVIDIA or AMD with >700 CUDA cores
Operating system	Windows, macOS, or Linux
Internet access	Minimum 100 Mbps
RAM (random access memory)	16–32 GB

3. Results

In the laboratory exercise, students used UAV photos to create an orthophoto mosaic and a DSM (Figure 5). The pre-assessment indicated that before the UAV laboratory exercise, most students were slightly (57.7%) or somewhat (26.9%) familiar with UAVs (Table 4). Over half of the students believed the UAV operation was a manual rather than an automated process (55.8%) (Table 4). Almost all students agreed that UAVs are essential for natural resource research (Table 4). While most students correctly answered questions about the final products of a UAV flight, students did not know the typical pixel resolution of UAV images, with only 26.9% answering correctly (Table 4).

The post-assessment answers indicated that the UAV module and laboratory exercise successfully educated students about UAVs and the end-to-end process starting with flight planning image collection, through image processing to obtain the orthophoto mosaic and DSM necessary for analysis as part of natural resource-related research. After completing the module, there was an increase in the number of students indicating their familiarity with UAVs as moderately familiar (+49.1% increase from pre-assessment) and as extremely familiar (+15.7%) (Table 4). Familiarity with the uses and data analysis process is a critical component of the module learning goals. There was a +44% increase in students correctly answering that UAV flights are mostly an automated process (Table 4). Accurate UAV data cannot be collected without automated flight and data processes, and this is often a misunderstood part of UAV use. Most students (92.1%) agreed that the UAV module and laboratory exercise were an effective way to learn about UAVs in natural resource research (Table 4).

Table 4. Results from the pre- and post-assessment surveys about remote sensing and UAVs (Fall 2021; FOR 4340/6340: GIS for Natural Resources, n = 52).

Survey Questions and Answers	Responses (%)		
	Pre-Assessment (n = 52)	Post-Assessment (n = 51)	Difference
Please, rate your familiarity with remote sensing.			
1 = Not familiar	19.2	0	−19.2
2 = Slightly familiar	38.5	0	−38.5
3 = Somewhat familiar	30.8	27.5	−3.3
4 = Moderately familiar	11.5	60.8	+49.3
5 = Extremely familiar	0	11.8	+11.8
A drone is a common term for an unmanned aerial vehicle (UAV).			
True	**98.1**	**100**	**+1.9**
False	1.9	0	−1.9
Please, rate your familiarity with UAVs/drones.			
1 = Not familiar	9.6	0	−9.6
2 = Slightly familiar	57.7	0	−57.7
3 = Somewhat familiar	26.9	29.4	+2.5
4 = Moderately familiar	5.8	54.9	+49.1
5 = Extremely familiar	0	15.7	+15.7
Which of the following is a product that cannot be created using a UAV?			
3D point cloud	30.8	5.9	−24.9
Aerial orthophoto	0	0	0
Digital surface model (DSM)	5.8	2	−3.8
Shapefile	**63.5**	**92.2**	**+28.7**
A UAV is an important tool for gathering information for natural resource research.			
True	**98.1**	**100**	**+1.9**
False	1.9	0	−1.9
What is the average pixel resolution for images taken by a UAV?			
1–3 mm	15.4	13.7	−1.7
1–3 inches	**26.9**	**78.4**	**+51.5**
1–3 feet	34.6	2	−32.6
1–3 m	23.1	5.9	−17.2
Is the operation of a UAV during flight typically a manual process or an automated process?			
Manual—the pilot must fly the UAV at all times with a controller	55.8	11.8	−44
Automated—the pilot does not need to fly the UAV with the controller during most parts of the flight	**44.2**	**88.2**	**+44**
What is the end result of a typical UAV flight?			
100's of individual photos	**71.2**	**92.2**	**+21**
One large orthophoto	1.9	0	−1.9
A digital surface model (DSM)	1.9	0	−1.9
An orthophoto and a digital surface model (DSM)	25	7.8	−17.2
To create an orthophoto and a digital surface model (DSM), you need to:			
Download these products from the UAV	9.6	3.9	−5.7
Process the individual images using software that creates an orthophoto and a DSM	**80.8**	**96.1**	**+15.3**
Download these products from the UAV's accompanying app	9.6	0	−9.6
The UAV simulation and laboratory was an effective way to learn about using UAVs for natural resource research.			
1 = Strongly disagree	-	0	-
2 = Disagree	-	0	-
3 = Neither agree nor disagree	-	7.8	-
4 = Agree	-	52.9	-
5 = Strongly agree	-	39.2	-

Note: Correct answers are shown in bold.

The UAV simulation videos in the module illustrated each step of the UAV flying process. Since the videos were uploaded to YouTube for sharing purposes, the number of views per video was tracked. The first video, pre-flight inspection, received 40 views out of the 52 students (77%). The second and third videos, flight planning and launch, received 33 and 32 views, respectively (63%, 62%). The final two videos, UAV bird's-eye view, and UAV landing, had 26 views, indicating 50% of students in the study watched all videos in the simulation, and viewership decreased with each successive video in the five-video series.

Student definitions of remote sensing improved in accuracy and detail after completing the UAV educational module (Table 5), illustrating that students better understood the topic after the UAV exercise. The concept of remote sensing is important in natural resources and other STEM fields because it is the critical source of information used to map and evaluate land cover and land cover change. Post-assessment student responses included specific information on how UAVs and other remote sensing systems can capture data.

The quiz evaluated the student's understanding and recollection of the material from the lecture, UAV simulation videos, and the laboratory exercise. Students were clearly instructed not to reference outside material or receive help from other students when taking the quiz to ensure it was an actual test of retained material. Overall, the students performed well on the quiz with an average score of 92%, a high score of 100%, and a low score of 70% from 51 students (Table 6). Ninety percent or more of the students answered seven of the ten questions correctly. The question with the lowest number of correct answers ("What is the first step when flying a UAV?") had 84% of students answer correctly. It took an average of 5 minutes and 18 seconds for students to complete the online quiz.

Student feedback (Table 7) about the module and laboratory exercise was positive, as students indicated they enjoyed the module subject matter and organization (Figure 6). The module enabled students to connect how they can use UAVs in their future careers. Students enjoyed using a new software program in the laboratory exercise. The main criticism was that students would like some portion of the exercise to work with the UAV in person. Some students mentioned that they would have liked a more challenging laboratory exercise with more application of the data created from the UAV images.

Table 5. Examples of unmatched student responses to the pre- and post-assessment open-ended question asking students to define remote sensing. Responses are compared from before and after completing the UAV module (Fall 2021; FOR 4340/6340: GIS for Natural Resources, n = 52 (pre-test), n = 51 (post-test).

Pre-Test Definition by Students	Post-Test Definition by Students
Remote sensing	
Collecting data from a distance.	Mapping the Earth's surface and its above-ground features using satellites, UAVs, and other applications.
Mapping the surface of the Earth from above.	Gathering data and physical characteristics from the reflectance of objects from a satellite.
Gathering information from an object without physically touching it.	Collecting information about Earth's surface and above-ground features using radiation, including visible light, infrared, temperature, etc.
Using aircrafts to collect images of the ground.	The use of technology to collect data about an area without physically being there.
Using a drone, satellite, or another device that can take readings from far away to measure something about the area.	Using sensors such as thermal, multi-spectral, and imaging sensors to collect data from a distance, such as using UAV or other flying technologies/satellites.

Table 6. Canvas quiz questions and results about remote sensing and UAVs (Fall 2021; FOR 4340/6340: GIS for Natural Resources, n = 52). The highest possible quiz score was 10. The average score was 92%, with the lowest score of 70% and the highest score of 100%. The average time to take the quiz was 5 min 18 s.

Quiz Questions, and Answers	Respondents	Responses (%)
What does the abbreviation UAV stand for?		
Unmanned aerial vehicle	**49**	**96**
Unoccupied air vehicle	0	0
Unmanned air vehicle	2	4
Unoccupied aerial vehicle	0	0
At Clemson, you do not need to be licensed under the FAA Part 107 regulations to fly a UAV.		
True	4	8
False	**47**	**92**
What is the height limit for flying a UAV above the ground?		
100 feet	1	2
250 feet	0	0
400 feet	**50**	**98**
750 feet	0	0
A digital surface model (DSM) contains height information of trees.		
True	45	88
False	**6**	**12**
Hyperspectral sensors on UAVs can help identify areas of drought stress.		
True	**49**	**96**
False	2	4
Which of the following is not a type of sensor used to collect information with UAVs?		
LiDAR	1	2
Multispectral	0	0
Pressure	**46**	**90**
Red, Green, Blue	4	8
Thermal	0	0
What is a digital surface model?		
Earth's surface and its above-ground features	**46**	**90**
Bare earth elevation	1	2
Height of trees and buildings above ground level	4	8

Table 6. *Cont.*

Quiz Questions, and Answers	Respondents	Responses (%)
UAVs can be flown in all weather conditions.		
True	1	2
False	**50**	**98**
What is the first step when flying a UAV?		
Plan the flight on the iPad	8	16
Launch the drone	0	0
Conduct a pre-flight inspection	**43**	**84**
Which of the following has a higher spatial resolution?		
NAIP aerial photo	1	2
UAV photo	**45**	**88**
30 m DEM	2	4
Landsat 9 satellite images	3	6

Note: Correct answers are shown in bold.

Table 7. Student responses to the post-assessment open-ended questions about their experience with the laboratory exercise grouped by theme (Redmond 2018). (Fall 2021; FOR 4340/6340: GIS for Natural Resources, n = 52).

Responses
T1. Enjoyment of Learning
I enjoyed seeing how my knowledge changed before and after learning about UAVs through the Google Forms questions.
Creating the DSM and Orthophoto was enjoyable, especially since we don't use software outside of ArcGIS Pro too often.
I liked learning how to effectively use UAVs, and I hope to use this information in the field in the near future.
I enjoyed this lab and thought it was well structured.
I really enjoyed the way this lab was set up and feel like I have a really good grasp of the material.
This was one of my favorite labs.
I really enjoyed looking at the details of the orthophoto image we created.
T2. Value of Multimedia
The visual demonstration helped portray what it is like to use a UAV. At first, I thought you had to manually fly them.
The videos were a helpful tool to understand the background of the UAV as well as looking at the DSM and orthophotos.
The visuals definitely helped me understand how this could be useful for many areas of research.
I enjoyed using pictures of a familiar area. For some reason, this made me more interested in what I was doing and allowed me to visualize and understand what I was doing on a deeper level.
I enjoyed watching the videos of the UAV flying process over the Tiger Band Plaza.
I thought it was done well, and the combination of the videos and the lab helped me understand the concepts well.
I liked being able to see the stark difference in resolutions from the UAV and the satellite images. I understand the importance and the value of them!
T3. Flexibility of Learning
I found it easy to go through the steps and learned a lot more than I knew beforehand about drones and remote sensing.
The exercise was a good way to see how people use drones to get data about the surrounding environment.
It was helpful seeing the data collected and then using the same data in lab.
Seeing the final product after creating the DSM was very satisfying.
It was neat to see how all the individual images came together to create the orthophoto.
Seeing how the images were collected was helpful—the videos were short but contained the necessary information, which I appreciated.
T4. Applicability of Content
I was happy that the instructions were very useful in completing this lab exercise.
I liked getting experience using Agisoft Metashape.
I think the exercise was very well organized and helped me to actually understand what I was doing.
I thought that this lab did a good job at providing a basic understanding of how UAVs are used and how to create orthophotos and DSMs from them.
I enjoyed how structured it was. I never felt lost.
I understood everything that was presented. It's a well-organized lesson.
T5. Criticism
Would have been cool to see a UAV in action, but this was a good at home intro.
It would have been more effective if we could learn how to use the drones in person.
Physical demonstration of UAV on lab talking about its parts and what we do before flight at least if possible (not UAV flight) on lab rather than video.
I think it would be easier if it was text to read instead of watching videos.
Having an in-person lab where the UAV could be demonstrated would be helpful.
The ArcGIS component could be more intensive/thorough than calculating tree heights.
I would have liked to see a bit more instructions after combining all of the images to do more with them.
You could bring the drone into class for a quick walkthrough of the flight plan and precheck, so we know how to use drone software.
The amount of separate parts for this assignment made me think that it was going to take me forever, so maybe combine some of the steps so there aren't as many parts.

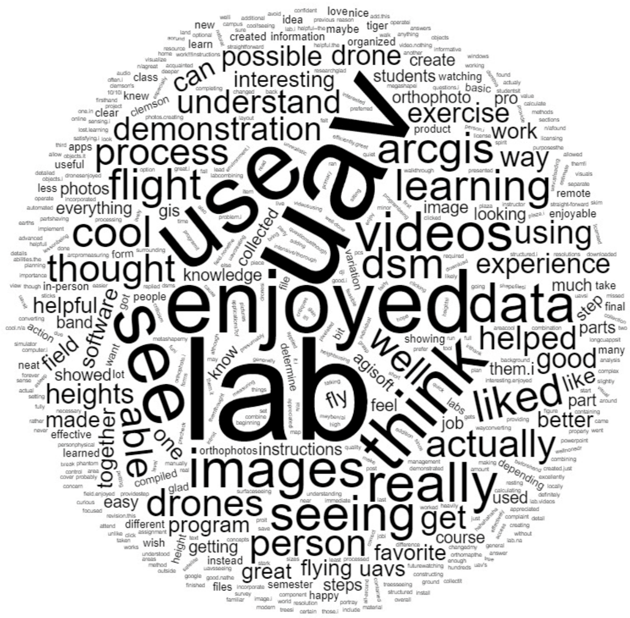


Figure 6. Word cloud from FOR 4340/6340 students' responses to open-ended post-assessment evaluation questions about the UAV module and laboratory exercise. Word size in the word cloud corresponds to the frequency of the terms used in the students' comments.

4. Discussion

This study examined the efficacy of using an online educational module and laboratory exercise to teach students about the general process of creating an orthophoto mosaic and DSM from UAV imagery. Students also learned how DSMs provide information about tree height. The teaching material and laboratory exercise were designed to teach students about UAVs virtually, so the module could be replicated by educators who do not have access to a UAV.

Providing students with virtual simulations of the UAV flight process introduces students to UAV flights for collecting data. Since UAV flights are controlled through companion applications, there is little need to teach students how to control the UAV with a hand-held manual controller. Therefore, this exercise illustrates that students can be introduced to using UAVs for research without the need for in-person instruction. By watching the UAV simulation videos in the educational module, students learn how to replicate the steps in person. The videos also provided important background information for the students necessary for them to complete the laboratory exercise, so the videos were a critical part of the education module. Using this methodology breaks down barriers for educators who do not have access to UAVs and provides students with the information needed to use UAVs in the future as UAV technology becomes more accessible. Since it has been increasingly important to teach students about UAVs to prepare them for careers in STEM [4,5], it is necessary to introduce students to UAVs, regardless of whether the instructor has access to a UAV and the requisite licensing/institutional support.

Recommendations for creating UAV teaching material are provided in Table 8. When designing UAV educational material, the first recommendation for educators is to choose a topic that integrates with UAV functionality. Many low-cost UAVs capture a series of aerial photographs that can be used to create both an orthomosaic image and a DSM that represents the height of objects. Orthomosaic images have a consistent scale across the image, making it possible to measure the location or extent of features visible in the photo using an online or desktop-based GIS system. The elevation information in the DSM can be used to evaluate the height of objects relative to the ground. For example, in this study, the UAV data were used to visually examine the study area and measure the heights of trees. If available, additional sensors beyond the more common RGB camera can be used to extend UAV education to topics beyond what can be determined from image and DSM evaluation. Mesas-Carrascosa et al. [38] instructed agriculture students to use UAVs for determining crop health metrics such as vigor and water stress using UAV integrated multi-spectral and thermal sensors. In another UAV education exercise, students used a UAV to visually examine drought impacts on lake volume and the surrounding area [39]. The UAV lessons and projects were tailored to the student's academic major in each instance. However, it would be possible using the proposed methodology to have subject-matter experts develop a range of different UAV exercises that could be shared globally to extend access for students where resources are not available for in-person UAV instruction.

Table 8. Recommendations for educators when designing UAV teaching experiences for students. Educators should answer the posed questions in sequence to help decide the best methods for the course.

Questions	Answer to Question	
1. Does your subject matter integrate with teaching UAV applications?	**Yes**	**No**
Consider what a UAV can measure: • Aerial photographs can be stitched together into an orthophoto mosaic of the study area, • Measurements of object height (buildings, trees, etc.) above the ground and the elevation of the study of the area can be estimated.		Think of alternative ways to use UAVs to study your topic. Examples of appropriate exercises: calculate the area of a specific object of interest, measure the height of objects, and visualize an area from above.
2. Do you have access to a UAV?	**Yes**	**No**
If you have access, consider the UAV flying and institution insurance regulations/requirements that may necessitate the pilot to be certified. Would a certification requirement limit your access to using the UAV?	Conduct in-person and hands-on learning opportunities.	Utilize online teaching material, simulations, and exercises.
3. How familiar are the students with UAVs?	**Basic**	**Advanced**
Consider the age of the students, as well as their technology literacy, when designing the UAV teaching material.	Focus on introductory teaching material on UAVs and simple exercises/demonstrations.	Explore more advanced UAV topics like sensor options. Have students conduct complex projects with UAV data.
4. Are you designing an entire course based on UAVs?	**Yes**	**No**
How much time do you have to dedicate to UAVs? This will determine the mode of instruction.	Incorporate a semester-long project for students to apply the skills and knowledge.	Teach a 1-day workshop or a laboratory exercise.
5. Where will you fly the UAV to collect data?	**Public land**	**Private land**
Consider location restrictions for UAV flights. Many countries restrict flight near airports and other protected areas like parks and military zones. Consider UAV flying regulations. In some countries, flying in the dark and flying over people are prohibited.		Acquire appropriate permission to fly from the owner.
6. Do you have access to UAV post-processing software?	**Yes**	**No**
Consider the software and hardware needs for processing the UAV imagery after collection.		Free or free-trial software options include DJI Terra, Drone Deploy, DroneMapper RAPID, Pix4DMapper, WedODM.

Note: Research involving animal and/or human subjects may be subject to the Declaration of Helsinki and must be approved by the appropriate institutional review board.

The second recommendation for designing UAV education material is to determine the availability of a UAV. If UAV access is limited from lack of resources or regulatory barriers, UAVs education can be taught in an online format through video simulations and exercises. This study utilized a series of UAV simulation videos to teach students the UAV flying process without being in person. He et al. [40] created a Virtual Simulation Experiment Teaching Platform for Unmanned Aerial Vehicle (VSETP-UAV) to teach students about using UAVs in remote sensing. Students set up a virtual UAV in this interactive virtual simulation and conducted all of the data acquisition and post-processing steps to create an orthophoto and digital elevation model (DEM). Even with access to a UAV, an educator must also consider the legal restrictions for UAV use in their country. Many country's regulations require UAV pilots to be certified after a period of training or after completing an exam [41]. The educator can take the time to become trained and certified to fly a UAV, or they can hire a licensed pilot to assist with an in-person exercise. In the United States, educational UAV flight falls under recreational use restrictions, which require all participants to complete The Recreational UAS Safety Test (TRUST) [1]. This test is freely available online, and students participating in a UAV educational flight must carry a copy of the test certificate [1].

The third recommendation for educators is to evaluate how familiar the students are with UAVs. If instructors are not aware of the students' current UAV knowledge, they can survey the students. In this study, students were provided with introductory lecture material about UAVs and videos illustrating how UAVs are used to gather information. The laboratory exercise taught students how to process the UAV imagery and create an orthophoto mosaic and DSM. Students also measured objects in the study area. If students have prior or more advanced knowledge about UAVs, the UAV education material can be more complex. For instance, lecture material can include more information on other sensors that can be integrated into UAVs like multi-spectral, LiDAR, and thermal. The activity can also be more involved, such as designing and building a UAV for specific engineering purposes [42]. Giurato et al. [42] taught an advanced UAV lab course in which engineering students designed a multirotor UAV and evaluated its flight. Considering the age and grade level of the student is also essential when creating UAV education content. For example, in a study outlining best practices for teaching about UAVs, Joyce et al. [5] suggest introducing elementary students to personal safety surrounding UAVs, introducing middle school students to UAV flight planning, and moving to more advanced UAV topics like remote sensing for students in high school and higher education.

The fourth recommendation for educators is determining the time they want to dedicate to teaching UAV information. The educational experience can be designed as a semester-long, quarter-long, or field-based course. For example, geography undergraduate students at Aberystwyth University attended a 10-day field course on South Island, New Zealand, where they learned how to collect UAV imagery of glacial morphology [43]. In this field course, students learned the principles of using UAVs for remote sensing and then applied the knowledge in a group project [43]. If the educator has a shorter amount of time, they can design a module that takes 1–2 weeks for students to complete. This study created a stand-alone module that students completed over two weeks. Another possible educator format is a hands-on workshop. For example, students at the United Arab Emirates University participated in a 1-day workshop. They completed hands-on field training using UAVs to acquire data, process the imagery, and create a 3D map of the campus [7]. Establishing the teaching time constraints will help educators decide how much material to cover and the best delivery format.

The fifth recommendation is for educators to decide where the UAV will be flown to collect data. In this study, the UAV was flown over an unoccupied campus area. Per university requirements, permission was obtained from emergency management, and the UAV was not flown over students or vehicles in accordance with the UAV flight requirements in the United States [1]. The UAV was flown close to mid-day to reduce the amount of shadow in the imagery, which can impact the final orthophoto mosaic of the study area. Educators should consider the weather conditions and time of day when flying the UAV. They should be aware of local UAV regulations that can differ from federal regulations.

The sixth recommendation is to investigate the software available for processing the UAV data. In this study, Clemson University had educational licensing for Agisoft Metashape [35], and it was already installed on lab computers for the students to utilize. If licensing for software is not accessible, several open-source software options can accomplish the post-processing. For instance, UAV image processing can be conducted through various software packages such as Drone Deploy [44], DJI Terra [45], Pix4Dmapper [46], and WebODM [47] without the need for paid licensing, although some software free-trial options have limited capabilities. Each software has specific hardware requirements and may have different output options, so the educators should evaluate the particular software capabilities and the availability of computing resources.

Overall, the key to teaching a successful course or exercise on UAVs should include setting clear learning objectives for the students and adapting the material accordingly. Educators must consider how teaching about UAVs fits into the broader course objectives when choosing the area of focus. Educators must consider their limitations, such as access to UAVs, the student's initial knowledge, the amount of time that can be dedicated to teaching UAVs, and where the UAVs will be flown. Finally, the educator must consider the final product of UAV education and what post-processing software will enable students to produce these products.

While going through each recommendation, educators may find that their access to UAVs is limited because of financial cost, training requirements, regulation barriers, or time constraints. This study shows that an online UAV education module and laboratory exercise can successfully teach students about UAVs without the need for costly in-person experiences.

5. Conclusions

This study evaluated the effectiveness of an online UAV module for teaching higher education students about UAV use in natural resource research. The improvement in the post-assessment survey and the 92% average in the knowledge retention quiz indicated that the module was effective. In addition, after completing the module, students had a marked increase in their self-reported familiarity with both remote sensing and UAVs, with more than 70% of students being moderately or extremely familiar with both topics. Student comments about the laboratory exercise in the module were positive and indicated the UAV module was enjoyable. Students found the module easy to follow, and the videos were a valuable way to learn about the topics.

Incorporating UAV information and exercises into the curriculum for STEM students is important for career preparation because of the widespread integration of UAVs as tools across many fields. The versatility of UAVs means UAV education opportunities can be uniquely tailored to the intended audience and provide problem-based learning for many STEM disciplines. Virtual exercises can provide students with a UAV educational experience regardless of their physical location or access to UAV equipment. Overall, this study illustrates the successful design of an online UAV education module and offers recommendations to educators for designing UAV exercises.

This study highlights the opportunity to broaden the integration of UAV training in higher education by developing domain-focused UAV training modules. These modules could provide training in general UAV concepts while providing specific examples of how UAVs are being used in relevant careers and research areas. Critical aspects of the proposed method include using videos to explain the data acquisition process and having the students create and analyze derived products. The ability to train students in UAV use and data acquisition is often limited by access to UAVs, particularly with LiDAR, hyperspectral, or thermal UAV systems that can cost tens of thousands of dollars to acquire. Developing and sharing UAV educational modules could greatly expand access. Future integration of virtual reality technology could help provide more realistic UAV training experiences.

Supplementary Materials: The full instructions for the UAV laboratory exercise can be accessed here: https://clemson.box.com/s/uj73t2tlqdjlcqrfn5t571xp2b36ebe7.

Author Contributions: Conceptualization, M.M.B., C.J.P.; methodology, M.M.B., E.A.M.; formal analysis, M.M.B.; writing—original draft preparation, M.M.B.; supervision, E.A.M.; writing—review and editing, C.J.P., E.A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by the Higher Education Challenge (HEC) grants program [grant no. 2020-70003-32310/project accession no. 1023532] from the USDA National Institute of Food and Agriculture. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of Clemson University (protocol code: IRB2020-257 and date of approval: 25 September 2020).

Informed Consent Statement: The IRB granted a waiver of informed consent.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Federal Aviation Authority. Unmanned Aircraft Systems. Available online: https://www.faa.gov/uas/2015 (accessed on 14 December 2021).
2. Watts, A.C.; Ambrosia, V.G.; Hinkley, E.A. Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use. *Remote Sens.* **2012**, *4*, 1671–1692. [CrossRef]
3. Salami, E.; Barrado, C.; Pastor, E. UAV flight experiments applied to the remote sensing of vegetated areas. *Remote Sens.* **2014**, *6*, 11051–11081. [CrossRef]
4. AL-Tahir, R. Integrating UAV into Geomatics Curriculum. In The International Archives of the Photogrammetry, Proceedings of the Remote Sensing and Spatial Information Sciences, Toronto, ON, Canada, 30 August–2 September 2015; Copernicus Publications: Toronto, ON, Canada, 2015.
5. Joyce, K.E.; Meiklejohn, N.; Mead, P.C.H. Using minidrones to teach geospatial technology fundamentals. *Drones* **2020**, *4*, 57. [CrossRef]
6. King, L.G.; McKim, A.J.; Raven, M.R.; Pauley, C.M. New and emerging technologies: Teacher needs, adoption, methods, and student engagement. *J. Agric. Educ.* **2019**, *60*, 277–290. [CrossRef]
7. Alkaabi, K.; Abdelgadir, A. Applications of unmanned aerial vehicle (UAV) technology for research and education in UAE. *Int. J. Soc. Sci. Hum.* **2017**, *5*, 4–11.
8. Cliffe, A.D. Evaluating the introduction of unmanned Aerial Vehicles for teaching and learning in geoscience fieldwork education. *J. Geogr. High. Educ.* **2019**, *43*, 582–598. [CrossRef]
9. Finn, R.L.; Wright, D. Privacy, data protection and ethics for civil drone practice: A survey of industry, regulators and civil society organizations. *Comput. Law Secur. Rev.* **2016**, *32*, 577–586. [CrossRef]
10. Everaerts, J. The use of unmanned aerial vehicles (UAVs) for remote sensing and mapping. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.-ISPRS Arch.* **2008**, *37*, 1187–1191.
11. Anthony, D.; Elbaum, S.; Lorenz, A.; Detweiler, C. On crop height estimation with UAVs. In Proceedings of the International Conference on Intelligent Robots and Systems, Chicago, IL, USA, 14–18 September 2014.
12. Berni, J.; Zarco-Tejada, P.; Suarez, L.; Fereres, E. Thermal and narrowband multi-spectral remote sensing for vegetation monitoring from an unmanned aerial vehicle. *IEEE Trans. Geosci. Remote Sens.* **2009**, *47*, 722–738. [CrossRef]
13. Han, X.; Thomasson, J.A.; Bagnall, G.C.; Pugh, N.A.; Horne, D.W.; Rooney, W.I.; Jung, J.; Change, A.; Malambo, L.; Popescu, S.C.; et al. Measurement and calibration of plant-height from fixed-wing UAV images. *Sensors* **2018**, *18*, 4092. [CrossRef]
14. Zarco-Tejada, P.; González-Dugo, V.; Berni, J. Fluorescence, temperature and narrow-band indices acquired from a UAV platform for water stress detection using a micro-hyperspectral imager and a thermal camera. *Remote Sens. Environ.* **2012**, *117*, 322–337. [CrossRef]
15. Rueda-Ayala, V.P.; Pena, J.M.; Hoglind, M.; Bengochea-Guevara, J.M.; Andujar, D. Comparing UAV-based technologies and RGB-D reconstruction methods for plant height and biomass monitoring on grass ley. *Sensors* **2019**, *19*, 535. [CrossRef]
16. Krause, S.; Sanders, T.G.M.; Mund, J.; Greve, K. UAV-based photogrammetric tree height measurement for intensive forest monitoring. *Remote Sens.* **2019**, *11*, 758. [CrossRef]

17. Corte, A.P.D.; Rex, F.E.; Alves de Almeida, D.R.; Sanquetta, C.R.; Silva, C.A.; Moura, M.M.; Wilkinson, B.; Zambrano, A.M.A.; Neto, E.M.C.; Veras, H.F.P.; et al. Measuring individual tree diameter and height using Gatoreye high-density UAV-LiDAR in an integrated crop-livestock-forest system. *Remote Sens.* **2020**, *12*, 863. [CrossRef]
18. Jin, C.; Oh, C.; Shin, S.; Njungwi, N.W.; Choi, C. A comparative study to evaluate accuracy on canopy height and density using UAV, ALS, and fieldwork. *Forests* **2020**, *11*, 241. [CrossRef]
19. Dunford, R.; Michel, K.; Gagnage, M.; Piegay, H.; Tremelo, M.L. Potential and constraints of unmanned aerial vehicle technology for the characterization of Mediterranean riparian forest. *Int. J. Remote Sens.* **2009**, *30*, 4915–4935. [CrossRef]
20. Siewert, M.B.; Olofsson, J. Scale-dependency of Arctic ecosystem properties revealed by UAV. *Environ. Res. Lett.* **2020**, *15*, 094030. [CrossRef]
21. Frakenberger, J.R.; Huang, C.; Nouwakpo, K. Low-altitude digital photogrammetry technique to assess ephemeral gully erosion. In Proceedings of the 2008 IEEE International Geoscience and Remote Sensing Symposium, Boston, MA, USA, 7–11 July 2008; pp. 117–120.
22. D'Oleire-Oltmanns, S.; Marzolff, I.; Peter, K.D.; Ries, J.B. Unmanned aerial vehicle (UAV) for monitoring soil erosion in Morocco. *Remote Sens.* **2012**, *4*, 3390–3416. [CrossRef]
23. Eltner, A.; Baumgart, P.; Maas, H.G.; Faust, D. Multi-temporal UAV data for automatic measurement of rill and interrill erosion on loess soil. *Earth Surf. Proc. Land* **2015**, *40*, 741–755. [CrossRef]
24. Bernard, E.; Friedt, J.M.; Tolle, F.; Marlin, C.; Griselin, M. Using a small COTS UAV to quantify moraine dynamics inducted by climate shift in Arctic environments. *Int. J. Remote Sens.* **2016**, *38*, 2481–2494.
25. Hodgson, J.C.; Baylis, S.M.; Mott, R.; Herrod, A.; Clarke, R.H. Precision wildlife monitoring using unmanned aerial vehicles. *Sci. Rep.* **2016**, *6*, 22574. [CrossRef] [PubMed]
26. Fortuna, J.; Ferreira, F.; Gomes, R.; Ferreira, S.; Sousa, J. Using low cost open source UAVs for marine wild life monitoring. In Proceedings of the 2nd IFAC Workshop on Research, Education, and Development of Unmanned Aerial Systems, Compiegne, France, 20–22 November 2013; pp. 291–295.
27. Mangewa, L.J.; Ndakidemi, P.A.; Munishi, L.K. Integrating UAV technology in an ecological monitoring system for community wildlife management areas in Tanzania. *Sustainability* **2019**, *11*, 6116. [CrossRef]
28. Sona, G.; Pinto, L.; Pagliari, D.; Passoni, D.; Gini, R. Experimental analysis of different software packages for orientation and digital surface modeling from UAV images. *Earth Sci. Inform.* **2014**, *7*, 97–107. [CrossRef]
29. Torres-Sanchez, J.; Lopez-Granados, F.; Borra-Serrano, I.; Pena, J.M. Assessing UAV-collected image overlap influence on computation time and digital surface model accuracy in olive orchards. *Precision Agric.* **2018**, *19*, 115–133. [CrossRef]
30. Gebrehiwot, A.A.; Hashemi-Beni, L. Three-dimensional inundation mapping using UAV image segmentation and digital surface model. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 144. [CrossRef]
31. Eriksen, C.; Ming, K.; Dodds, Z. Accessible aerial robotics. *J. Comput. Sci.* **2014**, *29*, 218–227.
32. Nitschke, C.; Minami, Y.; Hiromoto, M.; Ohshima, H.; Sato, T. A quadrocopter automatic control contest as an example of interdisciplinary design education. In Proceedings of the 14th International Conference on Control, Automation and Systems (ICCAS), Seoul, Korea, 22–25 October 2014.
33. He, Y.; Lu, H.; Song, Y.; Liu, L. Design and implementation of virtual simulation experiment system for acquisition and production of UAV real-scene 3D data. In Proceedings of the IEEE 4th International Conference on Automation, Electronics, and Electrical Engineering, Shenyang, China, 19–21 November 2021.
34. Valderrama, R.P.; Ocana, L.B.; Sheremetov, L.B. Development of intelligent reusable learning objects for web-based education systems. *Expert Syst. Appl.* **2005**, *28*, 273–283. [CrossRef]
35. *ArcGIS Pro: Release 9.1*; Environmental Systems Research Institute: Redlands, CA, USA, 2021.
36. Metashape; Agisoft. Available online: https://www.agisoft.com/ (accessed on 16 December 2021).
37. Clemson University. *Undergraduate Catalog System*; Clemson University: Clemson, SC, USA, 2021.
38. Mesas-Carrascosa, F.J.; Porras, F.P.; Trivino-Tarradas, P.; Merono de Larriva, J.E.; Garcia-Ferrer, A. Project-based learning applied to unmanned aerial systems and remote sensing. *Remote Sens.* **2019**, *11*, 2413. [CrossRef]
39. Gillani, B.; Gillani, R. From droughts to drones: An after-school club uses drones to learn about environmental science. *Sci. Child.* **2015**, *53*, 50–54. [CrossRef]
40. He, X.; Hua, X.; Montillet, J.P.; Yu, K.; Zou, J.; Xiang, D.; Zhu, H.; Zhang, D.; Huang, Z.; Zhao, B. An innovative virtual simulation teaching platform on digital mapping with unmanned aerial vehicle for remote sensing education. *Remote Sens.* **2019**, *11*, 2993. [CrossRef]
41. Stoker, C.; Bennett, R.; Nex, F.; Gerke, M.; Zevenbergen, J. Review of the current state of UAV regulations. *Remote Sens.* **2017**, *9*, 459–485. [CrossRef]
42. Giurato, M.; Gattazzo, P.; Lovera, M. UAV lab: A multidisciplinary UAV design course. *IFAC PapersOnLine* **2019**, *52*, 490–495. [CrossRef]
43. Williams, R.D.; Tooth, S.; Gibson, M. The sky is the limit: Reconstructing physical geography from an aerial perspective. *J. Geogr. High. Educ.* **2017**, *41*, 134–146. [CrossRef]

44. DroneDeploy. Available online: https://www.dronedeploy.com (accessed on 12 January 2022).
45. DJITerra. DJI. Available online: https://www.dji.com/dji-terra (accessed on 14 January 2022).
46. Pix4Dmapper. Pix4D. Available online: https://www.pix4d.com/product/pix4dmapper-photogrammetry-software (accessed on 14 January 2022).
47. WebODM. Open Drone Map. Available online: https://www.opendronemap.org/webodm/ (accessed on 12 January 2022).