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Identifying an Implementation Framework for Integrating Drones into STEM and Career Technology Education CTE Programs

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Abstract: As drone technology is rapidly becoming accessible to school children in terms of both low cost and ease-of-use, primary and secondary school teachers are beginning to consider where modern drones can play an important role in schooling. To date, there is very little empirical education research printed in the education research literature guiding innovative curriculum developers in the incipient domain of drone education. As a result, teachers interested in including emerging technologies in their classrooms are often at a loss of where to begin. Through clinical interviews with schoolteachers in the United States, our study identified five readily accessible "departure points" to include drones in contemporary STEM & vocational technology (CTE) school classrooms that help teachers address common curricular goals. Taken together, these interviews reveal that teachers using drones follow one of several distinct pathways as a first step toward achieving a widespread goal of teaching students to use modern technologies to construct, pursue, and communicate findings of fruitful research inquiries—the prevalence of which is not reflected in a comprehensive literature review. The five pathways for starting a successful drone education emerging from the interview data as dominant were: timed-racing trials; precision-flight obstacle courses; computer coding; videography; and domain-specific knowledge of drone operations laws and ethics.

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1. Introduction

Innovative applications of modern unmanned aerial systems (UAS) technology are rapidly influencing a wide range of research, development, military, work, school, and hobby realms [1–5]. Given the widespread use of professional and non-professional UAS—hereafter referred to simply as "drones"—there is considerable interest in determining how people best learn to fly and use drones [6]. If the broader drone community better understands how people come to fly and use drones, then drone education training programs can be formulated to target specific applications and be made more efficient. The end result will be better trained drone operators who fly safely, efficiently, and legally.

It is not that numerous drone education programs to prepare drone operators do not already exist—in fact, many already do: However, the vast majority of them either focus on helping nascent pilots acquire formal federal licensure or more experienced pilots earn advanced certifications [7–9]. In the United States, for example, numerous education programs are available to help pilots pass the FAA *Part 107 Commercial Drone Remote Pilot* licensure test. Costing around $300 USD each and lasting 16-36 hours, the reportedly most popular of these include: 1. University of Delaware: Ground School and Part 107 Test Prep; 2. Pilot Institute: Part 107; 3. Drone Pilot Ground School; 4. DARTDrones Flight School; and 5. Drone U [10]. These programs self-describe themselves as being highly successful: However, there is to date almost no systematic education research in the scholarly literature landscape describing the long-term effectiveness of such drone education programs.

What does exist in the scholarly literature on drone education does point to a number of disconnected education programs created on an *ad hoc* basis to fulfil an urgently tacit need for drone pilot training. In 2021, Thai researchers Bai, Chu, Liu, and Hui attempted to conduct a critical review scholarly work drones in education [11]. Concluding in their paper that drone education is well positioned for STEM education in particular—and computer engineering education specifically—their paper mostly reviews conference presentation abstracts rather than many formal scholarly journal articles. This lends weight to the notion that a scholarly view of drone education is still too nascent to appear widely when surveying the traditional scholarly education research literature base.

One does not often find substantive disagreement about what sorts of projects constitutes a STEM-centric project: Monitoring wildlife using drones [12] or inclusion of mathematics curricula in schools [13] inarguably are components of the STEM domain. But, at the same time, it is rather unclear what exactly is meant by the widely used but rarely carefully defined, broad phrase of 'drone education.' What is clear is that there are numerous different kinds and models of drones for different purposes that are poised to serve different educational functions [14,15] . In the same way, there does not seem to be a single drone model that works great for every application. Accordingly, such a widely ranging variability of drone equipment might account for the apparent lack of any single agreed upon educational purpose and training approach. Drone education could mean drone flight education, drone engineering education, drone 'computer coding for autonomous flight' education, or even 'analyzing data obtained by drones' drone education '*in the absence of any drone flight experiences at all'* [16,17]. Alternatively, successful 'drone education' program might simply be a highly attractive way to encourage college-bound students to pursue high tech STEM degrees with our without drones, such as the insightful dissertation work by Lamkin with Black male high school students [18], the Idaho *iDrone* program in the western United States [19], and the *drone@school* program in the Malaysian state of Kelantan [20] –all of which demonstrably promote STEM career pathways through the excitement that naturally surrounds the use of drones. These are all similar to the innumerable broadly STEM-based education programs where career education and promoting enthusiasm for following STEM career pathways education programs that include, perhaps not surprisingly, drones, as part of their marquee offerings [21–23]. While, researchers like Kahn and Aji in describing their work with disadvantaged Black students in the southern U.S. argue enthusiastically that their data convincingly demonstrates that using drones can enhance students' attitudes from a wide diversity of students toward STEM in general [24], no one seems to have found it necessary to publish a paper specifically on "do students think drones are cool?" as it seems self-evident to most anyone entrenched in the field.

While is certainly true that drone education could be naturally well situated within the STEM education domain [25], other authors argue that drone education is perhaps even better suited beyond STEM. In 2023, Slater and Sanchez argued that drone education should be an important part of work-based learning career and technical education efforts, such as in the domain of business education [26], construction management [27], and real estate education [28]. Moreover, there is fragmented by highly promising work in the domain of journalism education to teach journalism students how to augment their reporting with drones [29–31]. Much of this is similar to work by Badaluddin and colleagues who argue for the importance of teaching drone education in the context of agriculture education for high-tech farmers [32]. At the same time, some authors such as Mesas-Carrascosa and colleagues emphasize that teaching using a learner-centered project-based approach is more important than which specific scientific discipline is being used, although it is worth noting that they are focusing on teaching drones and remote sensing with college students [33], as does recent work published by Gillani describing the use of simple drones by young students for timely remote environmental monitoring of their local environment [34].

In the end, what one naturally wonders is: "how to best teach operators to be highly qualified and skilled drone pilots?" Based on their work with teaching some 6,000 novice drone pilots, Joyce, Meiklejohn, and Mead eloquently argue that the two key issues schools are facing in effectively teaching their students to fly drones are: (*i*) the limited flight skill and expertise of the classroom teacher and (*ii*) barriers created by the local regulatory rules and risk management concerns [35].

While we do know from work by Bryans-Bongey in the U.S. [36], Ng and Cheng in Hong Kong [37], and Khadri Ahmed in Egypt that targeted drone teacher training can substantively increase the number of schools using drones [38], what is missing from Joyce and colleagues' in-depth assessment seems to be any notion of the high startup financial costs to acquire drones in the first place, difficulty in finding appropriate flight facilities, and the lack of high-quality curriculum materials to support teaching with drones, as identified earlier by Slater, Biggs, and Sanchez by interviewing U.S. secondary school teachers [39], by Olaniyi, Nurudeen, and Muyideen studying Nigerian school teachers [40], and by Cliffe looking at university programs in the UK [41].

Perhaps because the inclusion of computer coding of unmanned robots and drones is gaining popularity as part of the US school STEM curriculum, what little scholarly research exists in the scholarly literature base about drone education is often regarding a focus on coding drones for autonomous flights. Based on their qualitative study of 30 high school students, Yepes, Barone, and Porciuncula propose that the already well-established methods of teaching in the domain of robotics coding are well aligned with what is needed to successfully teaching drone coding [42]. In much the same vein, Jovanovic and colleagues found that a three-day summer intensive program on coding unmanned guided vehicles broadly defined in the U.S. improved students' skills for more than 300 students that was structured around specific problems to solve in the form of designing automated "rescue missions" [43]. Similarly, the other type of computer coding for autonomous control we see in the literature are descriptions of teaching students to program drones to autonomously navigate a complex obstacle course [44]. What is obviously missing from this set of articles are robust descriptions of programs involving live, real-time drone flight.

Perhaps surprisingly, there seems as yet to be few researchers who are reporting on looking carefully at the real-time, actual precision flight skill end of the spectrum of drone operations, such as the impact of drone education programs focused on competitive racing [45,46] or on competitive drone film making and cinematography [47]. It is not that these programs do not exist—such as the well-respected U.S. college-level national drone racing championships hosted at North Dakota State University [48] or the commercially-based *MultiGP National Racing Championships* [49]—but the point is that few authors seem to be writing scholarly journal articles about such programs.

What is clearly needed for drone educators is a better understanding of what various pathways are available to institute a 'drone education" program. A more clearly implementation framework for focusing a drone education program would avoid teachers 're-inventing the wheel' as well as will help teachers 'leverage what interests and resources' already exist when deciding how best to start a drone education program. In the service of identifying a range of possible starting points for educators, this research project focuses on the overarching research question of, "what are some possible departure points and focus areas for initiating a successful drone education program in U.S. schools?"

2. Materials and Methods

2.1. Participants

The participants for this study were five practicing teachers in the western United States. There were three female teacher-participants and two male teacher-participants, all having more than 10-years of high school teaching experience, and all being older than 40 years of age. About half of the teachers had STEM teaching assignments while the other half had vocational and technical skill teaching assignments. None of the teachers held professional, commercial drone licenses, but all had passed a formal drone safety test. None of the participants had more than 5-years of hobby-level drone flight experience. The demographic differences among the teacher-participants were judged to be negligible.

These participants were selected using non-randomized 'purposive sampling method' [50] because these individuals were already known to the researcher, were known to have possessed knowledge about creating successful drone education programs, and were willing to be interviewed. The advantages of this judgement-based sampling approach are that it is highly efficient in that little researcher time is wasted with participants who do not possess sufficient knowledge to be informative. In the present research, the advantages of this strategy were judged to outweigh the well-known disadvantages of this non-randomized strategy, which include being subject to researcher bias and that the research results can be subject to less wide generalizability [51].

2.2. Method

In order to explore possible departure points practicing teachers are using to teach students with drones, an 'exploratory case study' approach was adopted. Exploratory case study is a widely used research method to examine specific phenomena—running a drone program, in the current case—that lack detailed preliminary research and conclusions [52]. This study approach was adopted because simply surveying a wide swath of teachers across the country with a quantitative survey would not yield the same information as in-depth qualitative interviews with knowledgeable interviewees.

Each participant was interviewed for about 40-minutes using a semi-structured interview. After the consenting process, the interview script questions were: (*i*) how long have you been teaching with drones and why did you start?; (*ii*) what is the current focus of your drone teaching activities and why are you doing it this way?; (*iii*) have you considered other approaches to teaching with drones and what are the relative merits of each?; and (*iv*) are you going to continue teaching drones in this manner or are you thinking of changing or expanding your drone teaching? The interviews were not recorded. The salient points emerging from the semi-structured interviews were captured in the researchers' field notes for thematic analysis [53]. It should be noted that the study's participant solicitation and consent process was approved by the researchers' overseeing human subjects institutional review board prior to the research.

3. Results

This section describes the results of the study's interviews. The results are organized around five dominant themes emerging directly from the data rather than listing the specific responses from each interviewee. Reporting the results in this way limits the risk of accidentally revealing the participants' identities that comes from publishing the results obtained from a small number of participants [54].

3.1. Teaching Basic Flight Skills

Among those teacher-participants interviewed for this study, the most common approach for structuring a drone education program was to focus on developing their students' flight skills. Teachers reported that offering students with the opportunity to fly drones was consistently best way to motivate initial student engagement. The most commonly used type of drone for teaching was a drone that had an automatic hover or automatic station-keeping capability, meaning a drone that hovers in place when the controls are released.

The teaching sequence that is most popular among those teachers interviewed was to first teach the most basic rules and regulations for their local community. Most often, this was done by having students take the online U.S. Federal Aviation Administration (FAA) T.R.U.S.T Safety test (described in more detail in *Section 3.6.* below). After certifying that students understood the basic regulations for flying drones, teachers quickly moved on to teaching flight skills.

After showing students how to turn on a drone and connect the drone to its remote controller, teachers consistently report first teaching and practicing takeoff and landing procedures. For most drones that have automatic hovering capability, these drones also have a takeoff and landing button: Activating the takeoff and landing button causes the drone to start the engines, rise to a height of about 1-meter, and then when selected a second time, causes the drone to land in the same place from which it initially launched.

After automatic takeoff and landing procedures are learned, teachers in this study consistently report most often teaching students to fly the drone first with only the throttle/yaw stick (generally the left-hand control) controller. By constraining students to only move upward and downward in a strict vertical column, novice students have fewer obstacles to avoid while learning how the throttle works. Only after teachers are convinced that a student can and will operate a drone vertically in a safe manner, do experienced teachers allow students to use the pitch and roll controller (generally the right-hand control) to fly the drone along the horizontal plane. Only after considerable flight experience, do teachers will allow their novice students to manipulate both control sticks at once. The most common flight practice tasks reported were: (*i*) takeoff, fly around an obstacle, and return to the launch site; (*ii*) takeoff, fly through an obstacle, and return to the launch site; and (*iii*) takeoff, avoid several obstacles, temporarily land on a given target, then return to the original launch site. After practicing these skills, perhaps for several weeks or more, teachers' reported approaches diverged significantly, and the various strategies are described in the following sections.

3.2. Timed-Racing Trials

Teacher-participants report that offering competitive racing opportunities seemed to be highly motivating to most student pilots. Racing took one of two forms. The first form of racing was to measure the time it took to complete a simple obstacle course. In this "race against the clock," the total time it took from leaving the launch site to successfully navigating obstacles and to land at the specified target—typically the launch site—was measured with a simple stopwatch. In this format, students are really competing against themselves, trying to improve their time to complete the task. This approach seems to have the advantage of not colliding with other drones and can be adapted easily for various skill levels.

Alternatively, some teachers have students compete 'two drones at a time' in head-to-head competition. Having two drones attempting to complete the same task at the same time in the same space creates a liability that drones might collide and damage one another. However, no teachers reported that this was a problem and instead reported an elevated excitement-level among students when two drones were flying side by side.

Most teachers reported that they did their drone racing indoors rather than outside. Part of this might be due to the geographic region in which this study took place—strong and gusty winds and low temperatures are common. Another reason that teachers often have their students fly indoors is that it avoids any conflict with local regulations that exist when flying out of doors, such as a school being too close to an airport for authorized flights. The most common facility used was the school gymnasium, but some teachers report using the school cafeteria, a large school foyer, or the school library—anything that had a relatively high ceiling. Other than having observers avoid the actual drone flight paths, no teachers reported implementing physical safety measures, such as safety netting or safety glasses.

3.3. Precision-Flight Obstacle Courses

About half of the teacher-participants interviewed were vocational technology teachers. In the U.S., a majority of vocational technology teachers engage their students in a national competition and certification program known as *SkillsUSA* [55]. SkillsUSA includes a drone competition, called *SkillsUSA sUAS Commercial Drone Competition* [56]. In this drone competition, students complete a knowledge test, complete a maintenance and repair task, and, participate in a precision-flight challenge. As a result, although people generally think of STEM as the dominant domain for teaching drone flying, a surprisingly large portion of drone education in the U.S. seems to be preparing vocational technology students to participate in this *SkillsUSA* sponsored program, which subsequently provides a natural onramp for a career in drone technology.

The precision flight skill portion of the *SkillsUSA* competition generally requires students to use a drone camera to identify information obscured from the drone pilot's viewpoint. Additionally, student pilots are required to precisely land on elevated platforms that include some degree of obstacles to be avoided, such as the one shown in Figure 1. Occasionally, student pilots are also required to move objects-such as lightweight plastic Ping-Pong balls—carefully using the drone's blade wash.

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Figure 1. *SkillsUSA*-style elevated precision landing pads for competition.

3.4. Computer Coding for Autonomous Flight

When surveying the literature about drone education, computer coding of drones for autonomous flight is the subject of most commonly formal published papers to date. Such an observation might suggest *prima facie* that a focus on computer coding might be the most common strategy for teaching students about drones . And, such an impression about the dominance of computer coding while teaching about drones would be consistent with the growing emphasis on computational thinking that is rapidly emerging in school curricula across the U.S. [57].

Only one teacher-participant in this sample spent more than 9 weeks of instruction teaching coding with drones, and only one other teacher in this sample mentioned spending more than one week of instructional time in this way. For these teachers, their stated goal of using coding of drones at all was to support broader goals of 'teaching computational thinking' including: breaking down complex problems into small steps, learning to sequence subroutines, recognizing and leveraging repeated patterns, and creating algorithmic solutions that can be readily changed and adapted. Although drones can be automated using a variety of software tools—*Tynker, Python, Open-CV, Swift, JavaScript, Node-JS*, among others—most teacher-participants in our sample reported using *DroneBlocks* alongside a Ryze Tello drone. An example of coding a Ryze Tello drone in *DroneBlocks* is shown in Figure 2.

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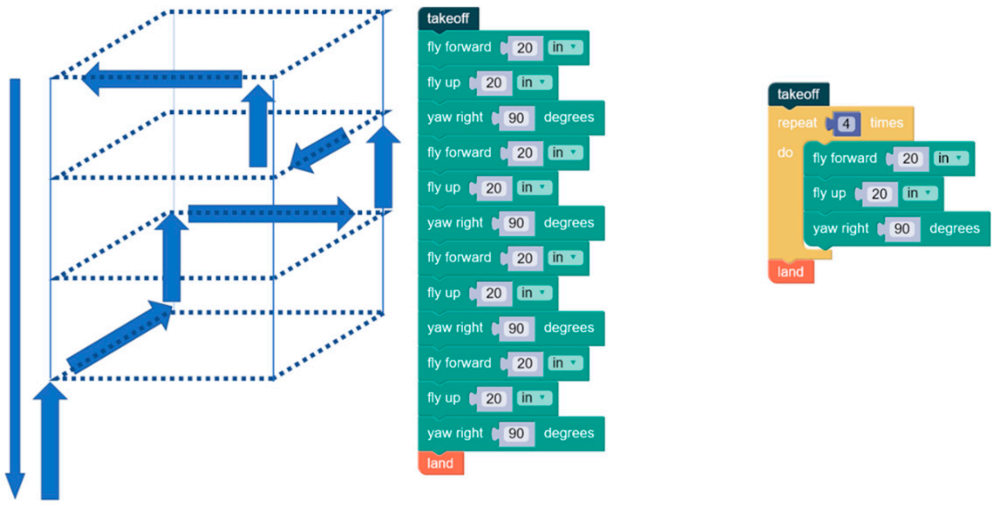

Figure 2. An example of drone coding for autonomous flight in *DroneBlocks*.

3.5. Videography

One of the most unique attributes of drones is their ability to access places and viewpoints difficult to acquire otherwise. As such, drones are particularly well poised to collect data, make maps, take photographs, and make videos. At the same time, many students are aware of the amazing videos, often set to popular music, available on the Internet. As but one example, the website AirVuz.com [58] hosts thousands of stunningly captivating videos on its website and awards prizes for its most popular submissions. Perhaps not surprisingly, many teachers desire their students to acquire solid flight skills so that they can learn to create high-quality, edited videos.

The teaching strategy to teach students how to make high quality drone-based films has three distinct phases. The first phase is to help students learn to fly. The second phase is to teach students what constitutes a high-quality drone film product. Teachers report that the best way to accomplish this is to have students view and rate that attributes of drone films that are already judged to be high quality, such as those award winners available from AirVuz.com. The attributes teachers report challenging their students to attend to are: flight-skill demonstrated during filming; digital editing skills exhibited by sequencing different videos; use of supporting music, narration, and/or text; adherence to a theme or storyline; and overall impression. The final teaching phase is to have students capture increasingly complex video clips with a drone—inside or outside—and teaching them to edit the video clips into a comprehensive presentation using simple digital video editing software, often on a smart cellphone.

3.6. Domain-Specific Knowledge of Drone Laws and Ethics

All teachers interviewed reported that students needed to know the most basic rules and regulations for drone flight, even if they were only going to be flying indoors where government rules and regulations do not apply. Most often, this was done by having students take the online U.S. Federal Aviation Administration (FAA) T.R.U.S.T Safety test [59]. The process of taking this entry-level Internet-based test provides learners with basic information and then "tests" their knowledge of this information.

All of the teacher-participants stated that they would like their drone-flying students over the age of 16 years to someday pursue and obtain a formal F.A.A. commercial drone pilots license, known as the FAA *Part 107 Remote Drone Pilot* license [60]. However, only about 1/3 had identified specific pathways to help their students acquire this license, and even then, not many students pursued this pathway [61]. Teachers suggested that fewer students than they would like actually acquire this

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license because of the high fee cost (about $175 USD), the difficulty of getting to an approved testing facility at a large airport, and the sheer volume of information that must be memorized to complete the test. Some teachers suggested that they have students who have no deep interest in learning to fly, but instead want to acquire as many formal certifications as possible, and simply want to pursue earning this federal level certification solely for the purposes of having it on their resume. Much of the information needed to be learned to successfully pass the test is provided by the F.A.A. at no cost online [62].

4. Discussion

The use of drones in schools for teaching have an innate ability to capture students' attention. Drones have the appeals of being high-tech, fast-moving, remote-control, and video capable. Teachers can use these attributes to motivate students learn in a variety of disciplinary domains—STEM, business, journalism, tourism, and vocational technology (CTE), among many others. The data gathered for this study confirms that a wide diversity of teachers are interested in leveraging available drone technology, but does not point to a single "best" approach to engage students in drone education. Illustrated in Figure 3, this study found teachers that focus on a wide range of starting departure points to implement drone education in schools: timed-racing trials; precision-flight obstacle courses; computer coding; videography; and domain-specific knowledge of laws and ethics.

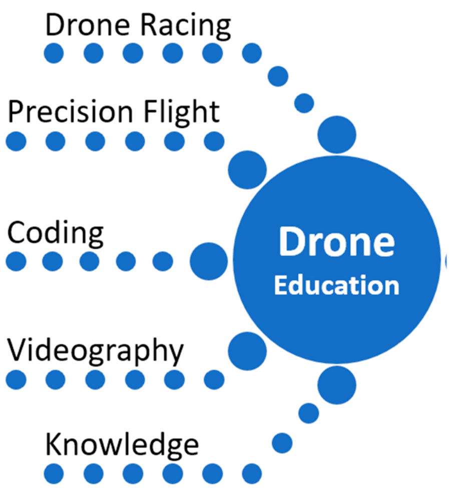

Figure 3. Non-hierarchical set of possible launching points for drone education programs.

One unexpected result of this study was related to the prevalence of teaching drones by emphasizing the computer coding of drones for autonomous flight. The critical literature review conducted for this study identified more articles and papers about coding drones for autonomous drone flight than any other specific drone education domain. However, any substantive emphasis on using computer coding when teaching students about drones was not reflected in this study's data. In contrast, teacher-participants in this study consistently talked about students' flight skills, either in service of fast precision flying or in service of obtaining data by taking advantage of the unique and efficient access of drones. In other words, the real-time flying of drones was by far the more dominant focus of these teacher-participants' efforts interviewed in this study and makes up 4/5 of the framework illustrated in Figure 3.

It is still unclear precisely what students are learning by participating in drone education. Perhaps this is true because of the overly broad definition of drone education. Or perhaps this is generally known because students are supposed to be motivated to pursue unspecified STEM or high-tech careers by participating in drone education, rather than learn specific concepts. Future researchers in drone education might find fruitful a research agenda identifying specific learning goals of drone education and then developing a consensus-based quantitative survey that educators could use to determine the effectiveness of a broad range of drone education programs.

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