Using Small UAS for STEM Education: Introducing Robotics and Mechatronics with Drones

Christian Janke, Stefan Kleinke, Kimberly Luthi, and Yuetong Lin

College of Aeronautics, Embry-Riddle Aeronautical University

jankec@erau.edu, kleinkes@erau.edu, taylok43@erau.edu, liny4@erau.edu

ABSTRACT

Several global developments point to importance of STEM-related education and studies. Every industry sector faces challenges in the recruiting of qualified personnel, due to retiring employees and general economic growth. Also, several domains, foremost automotive and aviation are undergoing a tremendous shift towards electrification to achieve sustainability. Hence, sparking the interest in STEM studies, education and vocational training cannot start early enough. This paper introduces the benefits of the educational use of sUAS by identifying core benefits in the three domains of learning – cognitive, affective, psycho-motor. Preliminary data and survey results from from several science, technology, engineering and math (STEM) drone providers worldwide will be used to identify and underline the benefits of this educational concepts.

Keywords: sUAS, STEM education, drones, robotics

1. Introduction

Small unmanned aircraft systems (sUAS), also known as drones, in their capacity as flying robots, provide exceptional opportunities to introduce general concepts of mechatronics and robotics to students in various age groups. Very small drones, suitable for the classrooms are between 50 and 150 grams in weight and mostly not bigger than the palm of a hand. They can be operated via remote control to cover aspects of kinematics, sensing, and localization. On the other hand, they also have excellent interfaces for pre-programmed and autonomous operations, utilizing block-based or script-based integrated development environments (IDE) to enable instruction of basic and advanced computer science concepts.

2. Literature Review

Over the last two decades, there has been an increased worldwide focus on getting more students to consider education and career choices in STEM fields [1–3]. On the one hand, an increasingly digitalized world generates a higher demand for people to rely on, understand, operate, and develop technology-driven solutions to common problems in the professional workplace as well as their private lives [1,4,5]. Thereby, the proficient use of information and communication technologies (ICTs) as cognitive tools [6, 7] has become a cornerstone of society and the educational sector. Associated competencies such as information and digital literacy, analytical and computational thinking, data-driven decision-making and critical thinking, communication and collaboration, as well as creative problem-solving were identified as crucial twenty-first century workforce skills [8, 9]. On the other hand, in the same timeframe, educational programs and learning initiatives in STEM fields have seen declining student interest and persistence [2, 10]. Despite initiatives to diversify the student body, the workforce in STEM-related fields remains one of the least representative of the general population in the US [1]. Part of this identified lack of motivation in students to pursue STEM-related careers and the associated education may be instigated by the mostly disengaging, content-driven, conventional format of these programs, in which highly complex technical knowledge is broken into its discipline-specific theoretical elements and then transmitted according to teacher-, textbook-, or curriculum-directed lesson plans [3]. As such, students are expected to acquire and memorize subject-specific knowledge and organize it around theoretical concepts without a clear understanding of when or how this knowledge will be applicable. In short, they do not know why they should learn [11].

Thus, already beginning in the 1990s, it was identified that such content-driven, teacher-centered, compartmentalized education seemed to produce undesired results, insufficiently preparing students for the workforce [5] as well as negatively affecting student engagement and motivation to learn [3]. As such, project-based activities in STEM education allow for active, collaborative, and situated learning that promote essential skills such as teamwork, task management and division of labor, as well as communication and negotiation of conflict [12, 13]. Furthermore, students seem to become more active agents of their learning, which may increase self-regulation skills and meta-cognitive awareness, as well as motivation [1, 9, 14, 15].

Such project-based learning (PBL) approaches are founded in a long history of constructivist and constructionist learning principles and supported by concepts in cognition and motivational theory. Over the years, various complementary schools of thought have emerged within constructivism, and the associated learning theories may all contribute to a better understanding of the learning processes involved in project-based activities. To advance the goal of integrative, trans-disciplinary STEM education through hands-on, collaborative PBL activities, one approach that has been increasingly applied over the last two decades is the utilization of educational robotics, in which robotic technology or its simulation is used to engage students with STEM concepts and problem-solving [6]. For example, [16] reported on the use of Arduino, a low-cost microcontroller for robotic and mechatronic applications, as a learning tool for robotics education, and [2] introduced electric circuitry and coding with a similar microcontroller to summer camp students. Zhong and Wang, in their study of pair learning [9], as well as [17] in their proposed STEM workshop, utilized mBot, a commercially available, low-cost educational robotic kit, while [18] and [19] reported on the use of similarly commercially available educational robotics kits: LEGO® Mindstorms.

Increasingly, aerial robotic platforms, also known as small unmanned aircraft systems (sUAS) or drones, are similarly employed in project-based STEM education. In [1], for example, the use of drones to introduce programming and cyber-security in a summer camp setting for minority students is reported, and [20] introduced sUAS-based robotic STEM education in an online workshop format.

As one of the few studies in the reviewed literature that investigated the use of robotics in PBL activities not directly related to the assembly or programming aspects, [21] explored sUAS usage for the collection of remote sensing data around which student projects revolved. In their study of teacher readiness to incorporate drone technology in the classroom, [22] identified a need for more professional development and training with such systems.

In the next section, we will show literature review for drones in STEM education. The outcomes support the suitability and effectiveness of such integration into learning activities of following areas:

- Development, design, and construction of the robot
- Programming and computational control of the robot
- Use of the robot in completion of real-world relevant tasks Analytical work with robot-generated data, such as Remote Sensing

3. Integration of sUAS in STEM Education

The use of sUAS in the classroom is an emerging trend in education. Robotic technology is growing in popularity in the workplace so it is critical to incorporate these technologies into instructional practices so that students are college and career ready. In [23], the authors made the case that "time has come for pioneers in STEM integration and technology education to utilize this cutting edge tool as both a topic and instructional device in K-12 education". The integration of sUAS provides students the STEM technology to inspire critical thinking, problem solving, and creativity. As pointed out in [24], the ability to integrate a singular technology into a classroom that has a broad range of applications is beneficial for students and has an easy entry point for teachers. In [25], authors discuss how drones can be integrated in education, propose a series of guidelines for educators on how to use drones in their classroom, and describe a five session (15-h) course designed to introduce young students to drones while motivating them to pursue further education in STEM.

Over the last decade or so, a significant effort has been made on incorporating sUAS into courses, curriculum, and programs, and the results have been shown at both K-12 schools and higher education. In [26], the authors review the application of drones in various educational environment and epitomize the ideas and implementations of drones for educational purposes. Classification of drones of different types used for educational purposes are outlined, and the frameworks proposed for drone based learning are reviewed and summarized.

An undergraduate module in "Applied Drone Technology" to enhance student engagement and learning of a new technology within a business school curriculum is introduced in [27]. The authors discuss the development strategy and issues the team encountered when trying to create something outside the usual core computing and business curriculum. In [28], the authors investigate dronagogy for higher education and develop a framework for dronagogy as a learning strategy. The study applies a case study using small autonomous drone integration in problem-based learning and MOOCs (Massive Open Online Course) using the pedagogy-space-technology framework. In [29], an sUAS education module and laboratory exercise for natural resource science students is developed. The study used a series of reusable learning objects (RLOs) to assess students' prior knowledge of remote sensing and sUAS. Students were taught the steps of sUAS data acquisition and processing through lectures and sUAS simulation videos. Students applied this knowledge by completing a laboratory exercise that used previously collected sUAS data. In [29], students in upper level GIS courses are trained on using sUAS technology with emphasis on sUAS operation, GIS data collection from sUAS, and advanced training in thermal IR image processing to meet the growing demand of sUAS savvy GIS workers. Drones are used to teach students the systems engineering design process (SEDP) and basic principles of aerospace engineering at the University of Alaska (UAF) [30]. A course that incorporates the application of UAS SEDP to satisfy operational needs of UAF's Alaska Center for Unmanned Aircraft Systems Integration (ACUASI) and associated research mission requirements is offered to: retrofit an existing Lockheed Martin Stalker aircraft with new electronics, and to completely build out a DJI S900 hexacopter. A collaborative effort to establish competitive sUAS educational program to create pipeline between two-year and four-year colleges is reported in [31]. In [32], an instructional module focusing on the use of sUAS with the primary objective of increasing the level of interest and engagement in science among younger students is introduced. The ARCS-V Model was combined with project-based learning to have students explore and master STEM concepts required to construct a remotely-operated quad-copter by having students produce a different operational product each week to demonstrate their understanding of targeted standards and objectives. [33] presents a robotic platform consisting of drone simulator and the navigation development framework that has been successfully used to develop a competition (called Drone Challenge), in which students had to program the navigation system for a simulated aerial robotic vehicle. Students design their proposals using a development environment based on Matlab/Simulink, then evaluate the performance of their designs in a simulation environment based on the robot operating system (ROS) and Gazebo.

[34], [35]

A virtual simulation module for high school seniors level that is less technical and more interactive is proposed in [36]. It is an integrated website which contains fundamental information on what a drone is and how to operate one. It incorporates an interactive game simulation in which the drone model created from 3D printing is integrated. In [37], an after-school enrichment activity offered sixth-grade students in groups of 10 three two-hour workshops entitled "Drones and Environmental Science" to explore the effects of the California drought in their community using an engaging sUAS. In [38], drones are used for integrated STEM education using inquiry-based and experiential learning approaches. This research paper is focused on the provision of connected ways of learning through integrated content knowledge and cross-curriculum links [38]. In [39], the authors have developed a sample engineering design based lesson for using quadcopters as a means to engage children in engineering, expose them to potential engineering-related careers at an early age, and integrate STEM learning through an engineering design challenge. In [40], a ninth-grade quantitative research course built on an AR Parrot 2.0 MUAV-based lab activity is introduced. The students designed a MUAV-based controlled experiment, collected their own data, used the collected data to formulate an understanding of the physics, and applied relevant mathematics to reach conclusions. [41] used the mini-drones to create a real-world, hands on STEM program to teach geo-spatial technology fundamentals with a problem-based learning approach. The framework of the program supports students to progress from basic knowledge and understanding through to synthesising ideas and creating new solutions. This program can be tailored to students across all age levels, from primaryelementary through to tertiary, and also for professional development training. A group of pre-service teachers was engaged in a case study conducted using a designed-based approach in [22], to assess their readiness and training needs for using drone technology in their teaching. Middle and high school students participated in The Idaho Drone League (iDrone) [42] to build, fly, and program drones and learned federal regulations and safety guidelines in a multiple-day-multiple-session workshops.

4. Core benefits in the three domains of learning

According to the generally accepted educational practice and learning principles, three main domains of learning exist, which are: the cognitive (thinking), the affective (social and emotional), and the psychomotor (physical/kinesthetic) domain. Here we will develop an introductory juxtaposition and classification scheme to classify the educational opportunities of sUAS targeting these three domains.

4.1 Cognitive domain

Drones are highly suitable to achieve theoretical knowledge transfer covered in the cognitive domain. Larger and very complex technological processes and instances can be conceptualized and visualized with a high relevance, immediate cognitive feedback, and real-world application. The following, non-exhaustive list introduces several examples for cognitive content and learning outcomes, potentially using educational sUAS.

- General math concepts such as vectors, algebra and geometry
- Electric propulsion and energy concepts in aviation and aerospace
- Micro Electro-Mechanical Systems (MEMS) as sensors for autopilots
- Micro-controller functionality and embedded systems
- Functionality of algorithms and taxonomy of computer languages
- Foundations of Computer Science - Input, Processing, Output
- Logic of block-based programming languages
- Syntax of script-based programming languages

4.2 Psychomotor domain

As described, drones are aerial robots moving in three-dimensional space. Therefore, they are highly capable of introducing and visualizing movement-related actions of a robots, also known as kinematics. Especially, a course of remotely piloted operation of a sUAS through a student with a handheld radios-controlled device flying through an obstacle is a highly motoric relevant scenario.

Due to the high level of support from the modern drones' flight controller, sensors and autopilot, a stable flight and hovering of the drone is very easy to achieve. Hence students can experience very fast success and learning curve, which leads to great excitement and high juxtaposition.

The level of support from the drones' autopilot can be flexibly adapted to assure increasing levels of difficulty and challenge from students. (Flight modes range from Level or Horizon up to Acrobatic mode, with smallest possible autopilot intervention)

The following, non-exhaustive list introduces several examples for pyschomotor learning, potentially enabled using educational drones:

- Spatial imagination and planning of three-dimensional movement
- Eye hand coordination
- Senso-motoric adaption
- Physics - real world experience of Newtons Laws and aerodynamics

4.3 Affective domain

The affective aspects of the learning domain can be addressed with small drones in an educational setting. Due to the very small weight, indoor operations, and high support from micro-autopilot onboard the drone, students can safely utilize functionalities very early and with great progress. This self-perceived progress to operate a small aerial robot not only boosts self-consciousness, but also raises further interest for the underlying concepts and principles from the STEM field.

Examples of learning outcomes associated with the affective learning domain include:

- Communication and coordination - Crew Resource Management between remote pilot and visual observer
- Intrinsic motivation to follow safety guidelines, procedures and checklists
- Responsible conduct with complex technology
- Realization of energy creation and conservation cycles relevant for future green and sustainable aviation concepts

5. Conclusions

The application of theory and engagement in the learning process through the use of small drones can inspire the next generation of the STEM workforce. Concepts such as basic knowledge and skills to operate small drones and integrated technologies is a good mechanism and aid to teach students STEM concepts and the interlacing of inter-disciplinary areas for problem-solving and collaborative learning. The review of literature and findings from this study showed that the integration of project-based learning scenarios through the application of sUAS offers excellent opportunities to introduce various STEM concepts from the fields of robotics, computer science, mechatronics, and aviation.

Institutions can take various approaches to systematically teach the application of STEM concepts learned through sUAS in their curriculum by covering a broad spectrum of subjects that are needed by industry in various sectors including mechanical design, electronics, feedback & control, computer vision, machine learning, and human-robotic interaction.

The paper summarized the authors' experiences facilitating both undergraduate research and teaching (sUAS) principles in courses across several disciplines. Also surveys and experiences from collaborative project-based learning opportunities available through programs such as MOOC's were used as baseline for the research. In 2020, the MOOC "Enhancing STEM Education with Drones" organized by Embry Riddle Aeronautical University, Worldwide

Campus, College of Aeronautics over 850 participants from all over world had opportunities to learn the basics of sUAS operations in educational setting, helping them to operate safely and responsibly.

For future improvement, we plan to develop more project-based learning scenarios for online settings, including, for example: 1) exploration of more sensors; 2) psychomotor learning; 3) electric propulsion and energy concepts; and 4) foundations of computer science - input, processing, output. By evaluating the effectiveness of the course content and lecture materials connected to projects using sUAS, students learning gains will improve as they learn more about general STEM fields as well as an improved understanding of interdisciplinary and creative thinking skills.

References

[1] J. Bhuyan, F. Wu, C. Thomas, K. Koong, J. Hur, and C.-h. Wang, "Aerial drone: an effective tool to teach information technology and cybersecurity through project based learning to minority high school students in the u.s," *TechTrends*, vol. 64, pp. 899–910, Apr. 2020.

[2] S. B. Nite, A. Bicer, K. C. Currens, and R. Tejani, "Increasing stem interest through coding with microcontrollers," in *2020 IEEE Frontiers in Education Conference (FIE)*, pp. 1–7, 2020.

[3] I. YEPES, D. A. C. BARONE, and C. M. D. PORCIUNCULA, "Use of drones as pedagogical technology in STEM disciplines," *Informatics in Education*, vol. 21, no. 1, pp. 201–233, 2022.

[4] D. Amo, P. Fox, D. Fonseca, and C. Poyatos, "Systematic review on which analytics and learning methodologies are applied in primary and secondary education in the learning of robotics sensors," *Sensors*, vol. 21, no. 1, 2021.

[5] S. Shanta and J. G. Wells, "T/e design based learning: assessing student critical thinking and problem solving abilities," *International Journal of Technology and Design Education*, pp. 1–19, 2020.

[6] I. Arocena, A. Huegun-Burgos, and I. Rekalde-Rodriguez, "Robotics and education: A systematic review," *TEM Journal*, vol. 11, pp. 379–387, Feb. 2022.

[7] S.-K. Wang, H.-Y. Hsu, T. C. Reeves, and D. C. Coster, "Professional development to enhance teachers' practices in using information and communication technologies (icts) as cognitive tools: Lessons learned from a design-based research study," *Computers & Education*, vol. 79, pp. 101–115, 2014.

[8] F. A. Phang, J. Pusppanathan, N. D. Nawi, N. A. Zulkifli, I. Zulkapri, F. K. Che Harun, A. Y. K. Wong, J. A. Alsayaydeh, and T. K. Sek, "Integrating drone technology in service learning for engineering students," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 16, pp. 78––90, Aug. 2021.

[9] B. Zhong and Y. Wang, "Effects of roles assignment and learning styles on pair learning in robotics education," *International Journal of Technology and Design Education*, vol. 31, no. 1, pp. 41–59, 2021.

[10] H.-Y. Hong, P.-Y. Lin, B. Chen, and N. Chen, "Integrated STEM learning in an idea-centered knowledge-building environment," *The Asia-Pacific Education Researcher*, vol. 28, no. 1, pp. 63–76, 2019.

[11] B. McKay, "STEM education: Practical applicationfor every learner," *The Midwest Quarterly*, vol. 61, no. 3, pp. 356–359, 2020.

[12] L. Chen, N. Yoshimatsu, Y. Goda, F. Okubo, Y. Taniguchi, M. Oi, S. Konomi, A. Shimada, H. Ogata, and M. Yamada, "Direction of collaborative problem solving-based STEM learning by learning analytics approach," *Research and Practice in Technology Enhanced Learning*, vol. 14, no. 1, pp. 1–28, 2019.

[13] A. Cohen and C. Nite, "Assessing experiential learning with a critical lens," *Sport Management Education Journal*, vol. 13, no. 1, pp. 1–10, 2019.

[14] M. Barak and M. Assal, "Robotics and STEM learning: Students' achievements in assignments according to the P3 task taxonomy—practice, problem solving, and projects," *International Journal of Technology and Design Education*, vol. 28, no. 1, pp. 121–144, 2018.

[15] A. Saad and S. Zainudin, "A review of project-based learning (PBL) and computational thinking (CT) in teaching and learning," *Learning and Motivation*, vol. 78, p. 101802, 2022.

[16] P. Plaza, E. Sancristobal, G. Carro, M. Blazquez, F. García-Loro, S. Martin, C. Perez, and M. Castro, "Arduino as an educational tool to introduce robotics," in *2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*, pp. 1–8, 2018.

[17] S. Chookaew, S. Howimanporn, P. Pratumsuwan, S. Hutamarn, W. Sootkaneung, and C. Wongwatkit, "Enhancing high-school students' computational thinking with educational robotics learning," in *2018 7th International Congress on Advanced Applied Informatics (IIAI-AAI)*, pp. 204–208, 2018.

[18] A. Merkouris and K. Chorianopoulos, "Programming embodied interactions with a remotely controlled educational robot," *ACM Transactions on Computing Education (TOCE)*, vol. 19, no. 4, pp. 1–19, 2019.

[19] B. Crnokić, F. Pehar, J. Spajiȁ, and I. Bagariȁ, "Stem classroom: Creating a pyton application for an EV3 brick robotic system used to transport 3D printed boxes," in *31st DAAAM International Symposium Proceedings*, 10 2020.

[20] J. Ryu, R. Walters, and H. Ziegler, "Interstate drone league (iDrone National) to promote hands-on remote STEM learning using cloud-based virtual meeting platforms in the global pandemic (COVID-19): iDrone National," *Journal of STEM Education: Innovations and Research*, vol. 22, no. 4, 2021.

[21] F. J. Mesas-Carrascosa, F. Pèrez Porras, P. Triviǹo-Tarradas, J. E. Meroño de Larriva, and A. Garcìa-Ferrer, "Project-based learning applied to unmanned aerial systems and remote sensing," *Remote Sensing*, vol. 11, no. 20, 2019.

[22] W. S. Ng and G. Cheng, "Integrating drone technology in STEM education: A case study to assess teachers' readiness and training needs," *Issues in Informing Science & Information Technology*, vol. 16, pp. 61–70, 2019.

[23] B. C. Preble, "A case for drones," *Technology and Engineering Teacher*, vol. 74, no. 7, p. 24, 2015.

[24] C. Carnahan, K. Crowley, L. Hummel, and L. Sheehy, "New perspectives on education: Drones in the classroom," in *Society for Information Technology & Teacher Education International Conference*, pp. 1920–1924, Association for the Advancement of Computing in Education (AACE), 2016.

[25] D. Tezza, S. Garcia, and M. Andujar, "Let's learn! an initial guide on using drones to teach STEM for children," in *International Conference on Human-Computer Interaction*, pp. 530–543, Springer, 2020.

[26] O. Bai, H. Chu, *et al.*, "Drones in education: A critical review," *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, vol. 12, no. 11, pp. 1722–1727, 2021.

[27] J. Kuzma, A. Robinson, K. Dobson, and J. Law, "Practical pedagogy for embedding drone technology into a business

and computing curriculum," *Journal of Education and Human Development*, vol. 7, no. 3, pp. 1–9, 2018.
[28] H. Norman, N. Nordin, M. A. Embi, H. Zaini, and M. Ally, "A framework of drone-based learning (Dronagogy) for higher education in the fourth industrial revolution," *International Journal of Engineering & Technology*, vol. 7, pp. 1–6, 2018.
[29] M. M. Bolick, E. A. Mikhailova, and C. Post, "Teaching innovation in STEM education using an unmanned aerial vehicle (UAV)," *Education Sciences*, vol. 12, no. 3, p. 224, 2022.
[30] M. C. Hatfield, J. Monahan, S. Vanderwaal, C. H. France, and L. W. Graves, "UAS design in active learning," in *ASEE Annual Conference and Exposition, Conference Proceedings*, (New Orleans, LA, United states), June 2016.
[31] Z. Siddique, A. L'Afflitto, W. Sun, J. Lee, S. Fowler, and W. Jones, "Developing diverse workforce for Oklahoma aerospace industry - collaboration between a two year and a four year institutions," *ASEE's Virtual Conference 2020*, 2020.
[32] M. Wright, "Increasing interest and engagement in elementary science with small unmanned aerial systems for science," in *21st Annual Technology, Colleges and Community Worldwide Online Conference Proceedings*, Apr. 2016.
[33] A. Bermúdez, R. Casado, G. Fernández, M. Guijarro, and P. Olivas, "Drone challenge: A platform for promoting programming and robotics skills in k-12 education," *International Journal of Advanced Robotic Systems*, vol. 16, no. 1, p. 1729881418820425, 2019.
[34] R. Shadiev and S. Yi, "A systematic review of UAV applications to education," *Interactive Learning Environments*, pp. 1–30, 2022.
[35] I. Majid, R. Sabatini, K. A. Kramer, E. Blasch, G. Fasano, G. Andrews, C. Camargo, and A. Roy, "Restructuring avionics engineering curricula to meet contemporary requirements and future challenges," *IEEE Aerospace and Electronic Systems Magazine*, vol. 36, no. 4, pp. 46–58, 2021.
[36] J. Espinola, J. E. D. Ignacio, J. P. L. Lacaden, C. B. D. Toribio, and A. Y. Chua, "Virtual simulations for drone education of senior high school students," *International Journal of Engineering and Advanced Technology*, vol. 8, no. 6 Special Issue 3, p. 220, 2019.
[37] B. Gillani and R. Gillani, "From droughts to drones," *Science and Children*, vol. 53, pp. 50–54, 10 2015.
[38] F. Sattar and M. Nawaz, "Drones and STEM education for the 21st century," in *Canada International Conference on Education (CICE)*, June 2019.
[39] G. J. Strimel, S. R. Bartholomew, and E. Kim, "Engaging children in engineering design through the world of quadcopters," *Children's Technology & Engineering*, 2017.
[40] H. M. Clever, A. G. Brown, and V. Kapila, "Using an AR drone lab in a secondary education classroom to promote quantitative research," in *2016 ASEE Annual Conference & Exposition*, (New Orleans, Louisiana), ASEE Conferences, June 2016.
[41] K. E. Joyce, N. Meiklejohn, and P. C. Mead, "Using minidrones to teach geospatial technology fundamentals," *Drones*, vol. 4, no. 3, p. 57, 2020.
[42] J. Ryu, S. LaPaglia, and R. Walters, "Idaho drone league (iDrone) to stimulate STEM workforce," *Journal of STEM Education: Innovations and Research*, vol. 21, no. 2, 2020.