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# INTRODUCEREA TEHNOLOGIILOR UAV ÎN ÎNVĂȚĂMÂNTUL STEAM: EXPERIENȚE ȘI MODELE DE BUNE PRACTICI

# INTRODUCTION OF UAV TECHNOLOGIES IN STEAM EDUCATION: EXPERIENCES AND BEST PRACTICE MODELS

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***Abstract.*** *Acest articol explorează integrarea tehnologiilor UAV (vehicule aeriene fără pilot) în educația STEM, evidențiind beneficiile pedagogice și practicile recomandate asociate. Studiul se bazează pe principiile învățării experiențiale și ale pedagogiei prin proiect, având ca scop transformarea predării tradiționale în activități interdisciplinare și aplicative. Metodologia a combinat instrumente cantitative și calitative: chestionare, interviuri, observații și analiza produselor realizate de elevi, implicând 58 de elevi și 12 profesori. Experiențele educaționale au inclus trei studii de caz reprezentative: măsurarea distanței și vitezei dronei, pentru aplicarea conceptelor de fizică; cartografierea terenului școlii, integrând geografia și informatica; proiectul eco-dronă, pentru monitorizarea deșeurilor și a vegetației locale. Rezultatele arată că utilizarea UAV-urilor crește motivația și implicarea elevilor, dezvoltă competențe digitale, colaborative și de gândire critică, și facilitează înțelegerea aplicativă a conceptelor STEM. Analiza calitativă confirmă formarea simultană a competențelor tehnice și sociale, iar produsele educaționale demonstrează aplicabilitate interdisciplinară. Sunt formulate recomandări pentru integrarea progresivă a dronelor în curriculumul STEAM, formarea continuă a cadrelor didactice și stimularea colaborării interdisciplinare. Direcțiile viitoare includ dezvoltarea platformelor virtuale pentru UAV și utilizarea inteligenței artificiale în analiza datelor educaționale. Acest model reprezintă un exemplu replicabil de bune practici STEAM centrate pe învățarea experiențială.*

***Cuvinte-cheie:*** *UAV, STEAM, învățare experiențială, interdisciplinaritate, bune practici educaționale.*

## 1. Introduction

In the last two decades, educational systems around the world have entered a broad transformation process, driven by the technological revolution and the acceleration of the digitalization of teaching and learning processes. The rapid advancement of emerging technologies – artificial intelligence, the Internet of Things, robotics, 3D printing and unmanned aerial vehicles (UAVs) – has led to a profound reconfiguration of traditional educational paradigms [2, 3, 4]. In this context, education is no longer focused exclusively on the transmission of knowledge, but on the development of complex skills, oriented towards problem solving, critical thinking, interdisciplinary collaboration and technological innovation.One of the most effective conceptual frameworks supporting this transition is that of STEM education (Science, Technology, Engineering, Mathematics), which integrates the scientific, technological, engineering and mathematical dimensions into a unified training system.

The STEM model promotes learning through discovery and applied projects, favoring the connection between theory and practice, offering students the opportunity to understand natural phenomena and technological processes in an integrated manner. Through this approach, the school becomes a space for research and experimentation, and the student – an active actor in the construction of knowledge. In this transformative framework, unmanned aerial vehicles (UAVs), also known as educational drones, offer remarkable educational potential. They allow the translation of theoretical content from physics, mathematics, geography, comp uter science or environmental sciences into concrete, attractive and motivational applications. The use of UAVs in the teaching process creates interdisciplinary learning contexts, in which students can explore the relationship between mathematical

concepts and real flight parameters (altitude, speed, acceleration), apply programming algorithms to control drone movements or analyze geospatial data to model the environment. In addition, drone activities stimulate scientific curiosity, encourage collaboration and develop algorithmic thinking – essential skills for the professions of the future.

The introduction of drones in STEM education also has a complex formative dimension: they become experiential learning tools, connecting students with the realities of science and the technological environment. Through direct observations, measurements, modeling and interpretations, students gain a deeper understanding of the principles of applied physics, mathematical structures and engineering processes. Activities with UAVs favor a pedagogy of action and reflection, in which learning is simultaneously cognitive and practical. Internationally, numerous educational initiatives have demonstrated the effectiveness of drones as teaching and research tools in the pre-university and university environment, but in the Eastern European space these practices are still in a consolidation stage. Therefore, a systematic analysis of implementation experiences and good practice models that can guide the sustainable adoption of UAV technologies in education is necessary. In this context, the main purpose of the research presented in this article is to explore the pedagogical potential of UAV technologies and their use in STEM education through experimental teaching activities. The study aims to outline a coherent and applied vision on how these technologies can contribute to the modernization of science education. To achieve this goal, the research was oriented towards achieving the following specific objectives:

1. Identifying the pedagogical advantages of using drones in the formation of scientific, technical and digital skills [1].
2. Description of experiences of implementing UAV technologies in STEM activities in pre-university education [6].
3. Presentation and analysis of models of good practices validated through educational projects, interdisciplinary workshops and school experiments, which can constitute methodological benchmarks for the expansion of these approaches in the future.

Through this approach, the article contributes to the foundation of a modern perspective on STEM education, in which technology becomes a means of scientific thinking, and drones – tools for exploration, measurement and reflection, capable of transforming learning into an authentic experience, oriented towards innovation and applied knowledge.

## 2. Theoretical and conceptual foundation

The rapid transformations of the contemporary world require a profound rethinking of the way in which education forms the necessary skills for the professions of the future. In this sense, STEM education (Science, Technology, Engineering, Mathematics) represents one of the most dynamic educational paradigms of the 21st century. It is based on the coherent integration of scientific and technical disciplines into a unitary learning framework, where the emphasis shifts from the accumulation of isolated knowledge to the development of the capacity for application, innovation and critical thinking.

2.1. The concept of STEM education and the extension to the STEAM model. The STEM model emerged in the early 2000s, in response to the need of modern economies for specialists with transversal skills in science and technology. Over time, the concept evolved towards the STEAM paradigm, which also includes the artistic dimension ("A" – Arts), recognizing the role of creativity and design in scientific innovation [8]. In this framework, the educational process is no longer limited to the transfer of knowledge, but becomes a holistic experience, in which students design, experiment, evaluate and create original products, based on the understanding of scientific mechanisms.

The STEM approach stimulates visual and creative thinking, encouraging students to find original solutions to complex problems. This dimension is essential in the context of the use of drones, where flight design, visual data analysis and interpretation of natural phenomena involve both scientific rigor and aesthetic sensitivity and imagination.

2.2. UAV – technological and educational tool. Unmanned Aerial Vehicles (UAVs), also known as drones, are technological systems capable of autonomous or remotely controlled flights, equipped with sensors, cameras or other measuring devices. Initially developed for military and scientific research purposes, UAVs have become, in the last decade, affordable and versatile tools, with extensive applications in agriculture, surveying, archaeology, environmental monitoring and, more recently, in science education [5].In an educational context, UAVs offer unique opportunities for experiential and interd isciplinary learning. Through them, students can connect abstract notions of physics (forces, trajectories, velocity, gravity) with direct observations and empirical measurements. For example, analyzing the flight of a drone allows for the application of equations of motion, the study of vectors and tilt angles, or the determination of altitude based on sensor data. Moreover, UAVs facilitate collaborative and creative activities, in which students plan flight missions, solve technical problems, program trajectories, or interpret the images obtained. These activities develop algorithmic thinking, digital skills, and engineering skills, strengthening the connection between STEM fields [7].

2.3. Theoretical framework of learning through projects and discovery. The integration of drones into education is based on the principles of Project-Based Learning (PBL) and Inquiry-Based Learning (IBL).

- Project-based learning (PBL) involves students engaging in authentic, interdisciplinary activities that start with a real-world problem and end with a concrete product: a presentation, an aerial map, a digital simulation, or a physical model. In the case of drones, projects can include, for example, measuring the distance between two points through autonomous flight, estimating wind speed, mapping a green area, or analyzing the environmental impact of waste [9, 10, 11].
- Inquiry-based learning (IBL) emphasizes the active role of the student in formulating hypotheses, collecting data, and interpreting results. The drone thus becomes a tool for scientific investigation, and the student becomes the researcher who applies empirical methods and logical reasoning to explain observed phenomena. These two educational paradigms contribute to the formation of applied scientific thinking, based on experimentation, reflection, and critical interpretation of data, essential skills in STEM education.

2.4. Skills developed through the use of UAVs in education. Specialized literature emphasizes that the introduction of UAV technologies into the teaching process supports the development of a complex set of transversal skills:

a) Scientific skills – by applying physics and mathematics concepts in real-world contexts.

b) Technological and digital skills – through the use of sensors, software applications and flight programming.

c) Engineering skills – through the design and calibration of UAV systems.

d) Social and collaborative skills – through team activities and cooperative problem solving.

e) Creative and visual skills – through aerial image processing, 3D model development and aesthetic interpretation of data.

This broad spectrum of skills confirms the integrative and transdisciplinary character of UAV-based education and supports the idea that technology, when used pedagogically, becomes the catalyst for deep and relevant learning.

2.5. Regulatory framework and international directions. The integration of UAV technologies in education is in line with the strategic recommendations formulated by international bodies such as UNESCO, the European Commission and the OECD, which promote digital education as a pillar of sustainable development. Framework documents such as the Digital Education Action Plan (2021–2027) and DigCompEdu, emphasize the importance of training digital skills applied in practical and interconnected contexts.At the same time, more and more countries are introducing national STEM training programs based on robotics and drones, as a means of attracting young people to the scientific and engineering fields. Therefore, the theoretical foundation of this research is based on the convergence of STEM education, the project-based learning paradigm and the technological potential of drones, seen as environments for scientific exploration, creation and development of 21st century skills. This interdisciplinary approach is the starting point for the analysis of educational experiences and models of good practice presented in the following sections.

**3. Methodology and research design**

This subchapter presents the methodology and design of the research on the integration of drones in STEM education. The study aims to assess the impact of UAVs on student skills and identify good educational practices. The research uses a mixed design, combining quantitative analysis with qualitative data interpretation. This approach allows for a rigorous examination of how UAV technologies support interdisciplinary learning and student creativity.

3.1. Research purpose and objectives. The main goal of the research is to analyze the impact of integrating UAV technologies into the STEM educational process and to identify models of good practices that can be replicated in various school contexts. The research aims to highlight how activities based on the use of drones contribute to the development of students' scientific, technological and creative skills. The specific objectives are:

♦ Determining teachers' and students' perceptions regarding the relevance of using drones in STEM activities.

♦ Analysis of the degree of curricular integration of UAV technologies in science and mathematics disciplines.

♦ Identifying good practice models that foster project-based learning and interdisciplinary collaboration.

♦ Formulation of an applicative conceptual model for integrating drones into STEM education, based on documented educational experiences.

3.2. Research design. The study was conducted based on a mixed design (qualitative-quantitative), which combines statistical analysis of empirical data with narrative interpretation of educational experiences. The research was structured in two stages:

• Exploratory stage – aimed at the analysis of specialized literature and international educational documents on the integration of UAV in STEM education.

• Empirical stage – involved the implementation of pilot teaching activities, followed by data collection through standardized instruments (questionnaires, interviews, direct observation).

This design allows for triangulation of results, ensuring the validity and consistency of interpretations.

3.3. The sample and the research context. The research was conducted during 2024–2025, in the Military College, where STEM training programs were implemented using educational drones.

The sample consisted of:

o 58 students aged 15–19;

o 12 teachers from the fields of mathematics, physics, computer science and environmental sciences.

The selected institution has the minimum infrastructure required for UAV activities (educational drone, controlled flight space, trajectory and image analysis software). The selection criteria for the participants were: relevant teaching experience, willingness to collaborate interdisciplinary and interest in modern technologies.

3.4. Research methods and tools. To collect data, complementary methods were used, specific to applied educational research:

• Questionnaire – was applied to students and teachers to assess perceptions of the usefulness and attractiveness of UAV activities, the level of involvement and the degree of perceived difficulty.

• Semi-structured interview – provided an in-depth perspective on how teachers plan, implement and evaluate drone activities.

• Direct observation – allowed the analysis of students' behavior during practical activities (cooperation, problem solving, application of theoretical concepts).

• Analysis of educational products – projects made by students (aerial maps, 3D models, flight simulations, observation reports) were examined to assess the level of competence achieved.

The research instruments were validated through consultation with STEM education experts and pilot-tested to verify the clarity and relevance of the items.

3.5. Procedure for conducting the educational experiment. The activities were structured into four interdisciplinary teaching modules, each lasting 2–3 weeks:

♦ Physics of flight and principles of aerodynamics – students studied the forces acting on UAVs and calculated flight parameters (speed, height, angle of inclination).

♦ Trajectory mathematics – concepts of analytical geometry and trigonometry were applied to determine coordinates and optimize flight paths.

♦ Digital mapping and image analysis – students used specialized software to process aerial images and identify environmental changes.

♦ Final interdisciplinary project – student teams carried out a practical mission: "Monitoring the green spaces around the College", applying all the knowledge acquired.

The activities were documented through observation sheets and reflective journals, completed by students and teachers.

3.6. Data analysis. Quantitative data were analyzed using basic statistical indicators (frequencies, means, standard deviations) to identify general trends regarding perceptions and impact of UAV

activities. Qualitative data (interviews and observations) were subjected to a thematic analysis, aiming to extract the categories: motivation, collaboration, creativity, technical difficulties and curricular integration. Data triangulation allowed the formulation of robust interpretive models, which correlate concrete educational experiences with STEM pedagogical principles.

3.7. Research limitations. Although the research provides relevant results, there are certain limitations:

- relatively small sample size;
- local nature of the implementation (only one institution);
- limited availability of technological resources (limited number of drones and educational software).

However, the proposed methodology has a replicable and adaptable nature, and can be extended to different educational contexts, including at the university level or in extracurricular programs.

3.8. Methodological synthesis. The research design confirms the methodological potential of UAV technologies as integrated learning tools. The applied methodology combines the exploratory dimension (study of perceptions and attitudes) with the applicative one (actual implementation of STEM projects), creating a coherent framework for analyzing the educational impact and formulating models of good practices.

**4. Results and discussions**

The subchapter presents the results and discussions on the impact of UAVs in STEM education. Data analysis highlights the increase in student motivation, the consolidation of theoretical skills and the development of collaboration skills. Teachers recognize the interdisciplinary value of drones, but emphasize the need for adequate training and resources. Student observations and projects show the concrete application of knowledge and the development of engineering thinking. Overall, UAV technology is confirmed as an effective tool for experiential learning and authentic assessment.

4.1. Students' perceptions of the use of drones in STEM activities. The analysis of the questionnaires applied to the 58 students revealed a predominantly positive attitude towards educational activities based on the use of drones.

• 85% of respondents said that using UAVs increased their motivation to study science;

• 78% said that hands-on activities with drones helped them better understand mathematical and physical concepts;

• 72% said that teamwork experiences helped develop collaboration and problem-solving skills.

Students also noted that “the actual drone flight turns theory into experience” and “the data collected by the drone makes them see math in action.” This association between physical activity and theoretical concept confirms the hypothesis that experiential learning facilitates deep understanding and long-term retention of knowledge.

4.2. Teachers' perceptions of the integration of UAVs into the curriculum. Semi-structured interviews conducted with 12 teachers revealed four main directions:

♦ Interdisciplinary relevance – teachers emphasized that drones can be used at the intersection of multiple disciplines (mathematics, physics, geography, computer science, environmental sciences), providing an authentic integrated learning framework.

♦ Formative value – teachers observed a significant increase in students' interest in scientific content and active involvement in practical activities.

♦ Technical difficulties – lack of adequate equipment, programming skills or controlled flight spaces were cited as major obstacles.

♦ The need for continuous training – teachers consider it essential to organize training courses on the didactic use of drones and associated software tools.

Overall, educators recognized the transformative potential of drones in STEM teaching, believing that they facilitate a shift from transmissive teaching to discovery and project-based learning.

4.3. Observations from experimental activities. Analysis of direct observations and reflective journals provided valuable insights into the dynamics of educational activities with UAVs.

• In the flight physics activities, students demonstrated a visible increase in the ability to apply mathematical formulas for calculating speed and altitude.

• In the digital mapping projects, they demonstrated operational autonomy in using image analysis software and presented concrete results (3D maps, topographic models).

• In the flight planning and execution sessions, effective team coordination behaviors were observed, with the assumption of roles (pilot, data analyst, programmer).

The observing teachers noted that students learned not only science, but also discipline, responsibility, and strategic thinking, as the use of UAVs involves procedural rigor and attention to safety.

Thus, the drone activities functioned as mobile learning laboratories, stimulating cooperation, critical reflection, and integrated technical skills.

4.4. Analysis of educational products. The final projects carried out by the student teams – especially the mission „ Monitoring the green spaces around the College" – provided concrete evidence of the application of interdisciplinary knowledge:

– Students used GPS coordinates and trigonometric formulas to calculate distances and areas of mapped areas.

– They applied physics principles (acceleration, tilt angle) to optimize trajectories.

They analyzed aerial images to identify areas affected by erosion or local pollution.

– The quality of the projects was assessed based on three criteria: scientific accuracy, degree of interdisciplinary integration and creative originality.

The results showed that:

- 65% of the projects reached an advanced level of STEM integration;
- 25% had a satisfactory application;
- only 10% required additional guidance.

This distribution indicates that drones can function as tools for assessing STEM skills, through visible and measurable products.

4.5. Thematic analysis of qualitative data. Thematic analysis of interviews and reflective journals led to the outline of five dominant conceptual categories that define the educational experience with UAVs:

***Table 1. Thematic analysis of qualitative data***

| Thematic category | Synthetic description | Examples of manifestation |
|---|---|---|
| Motivation and involvement | Increasing interest in science due to the practical and visual nature of the activities | "Flying the drone made me understand why angles and vectors matter" |
| Interdisciplinary collaboration | Teamwork between students and teachers from different fields | Joint projects between mathematics and computer science |
| Creativity and engineering thinking | Developing original solutions for UAV missions | Autonomous flight and 3D mapping projects |
| Autonomy and responsibility | Taking on roles and following safety protocols | Students coordinate the flight plan without assistance |
| Technical difficulties | Calibration, connectivity, and weather issues | Limitations resolved through software adaptation and simulation |

This synthesis reveals a coevolution of technical and social skills, which confirms the complex nature of STEM education mediated by UAV technology.

4.6. Discussions and interpretations. The results obtained confirm the working hypothesis that the integration of drones in STEM education has a significant impact on the quality of learning, both by increasing student motivation and by strengthening applied skills.

From the perspective of constructivist theory, the use of UAVs facilitates active learning through direct experience, and from the perspective of projective pedagogy – promotes problem-based learning (PBL) and interdisciplinary collaboration.

Compared to traditional methods, UAV activities:

- provides immediate feedback through visual and measurable results;
- stimulates conceptual integration between mathematics and applied sciences;
- creates authentic assessment contexts, where success is reflected in the final product and the ability to interpret real data.

Thus, UAV technology becomes not just a teaching tool, but a complex learning and research environment, in which students are trained as mini-researchers, developing cognitive, practical and metacognitive skills.

4.7. Partial conclusions.

♦ UAV technologies contribute significantly to increasing student motivation and involvement in STEM activities;

♦ Their integration determines the development of complex skills – scientific, technical, collaborative and creative;

♦ Hands-on activities with drones foster authentic interdisciplinary learning and the formation of engineering thinking;

♦ Technical limitations can be overcome through teacher training and institutional educational partnerships;

♦ The developed good practice model is replicable and can be adapted to various curricular contexts and educational levels.

## 6. Discussions

♦ **Interpretation of the results in the current educational context.** The results obtained confirm the global trend of integrating modern technologies into educational processes, especially in STEM fields, where the emphasis is shifting from theoretical teaching to learning through experiments and projects. The introduction of drones (UAVs – Unmanned Aerial Vehicles) in teaching activities has generated an increased level of involvement, motivation and curiosity among students, demonstrating the potential of these technologies to transform the traditional lesson into an interactive, student-centered experience. Against the backdrop of accelerated digitalization and labor market demands, UAV-based approaches align perfectly with the principles of education 4.0, where the emphasis is on interdisciplinarity, critical thinking and problem solving in real contexts.

♦ **Impact on the formation of transversal skills.** Students' participation in activities involving the use of drones contributed significantly to the development of digital and engineering skills, to the strengthening of collaborative skills and to the stimulation of critical thinking. For example, in the practical projects, students were involved in complex activities that required team coordination, programming, interpretation of data collected by sensors and mathematical analysis of the results. In this sense, UAVs become multifunctional pedagogical tools, capable of integrating contents of physics, computer science, applied mathematics and environmental education, thus contributing to the formation of transversal competences defined by the European Framework of Key Competences for Lifelong Learning (2018).

♦ **Difficulties encountered.** The implementation of UAV technologies in the educational environment can encounter a number of challenges, especially related to logistical and regulatory aspects. In some institutions, the lack of safe flight spaces or the necessary authorizations for the operation of drones limits the practical applicability of the planned activities. Also, the costs of equipment and their maintenance can exceed the financial possibilities of schools. Another major obstacle is the level of training of teachers. The integration of drones requires technical skills, but also the ability to correlate technology with pedagogical objectives. In this context, the development of continuous training programs and methodological guides for STEM teachers is required.

♦ **Analysis of project sustainability and expansion prospects.** In order for the introduction of UAVs in education to become a sustainable practice, it is necessary to create stable partnerships between educational institutions, educational authorities and the technology sector. Pilot projects can be gradually expanded by involving regional STEM centers of excellence, by accessing European funds for the digitalization of education and by developing open educational resources (OER) specific to the use of UAVs. In the medium term, a feasible model is the integration of drones into optional subjects or extracurricular modules, oriented towards learning through interdisciplinary projects and education for sustainability.

♦ **Relevance for military, technological or vocational education.** Within military or technical institutions, the use of UAVs has a dual relevance: educational and operational. Beyond training STEM skills, these technologies develop strategic thinking, precision, responsibility and the ability to react quickly – essential qualities in the training of military personnel and aviation technicians. Also, UAV-based educational projects can be adapted to vocational training scenarios, such as environmental

monitoring, land mapping or natural resource management, contributing to the training of a generation of specialists capable of interacting effectively with autonomous technologies and intelligent data analysis systems.

**7. Conclusions**

♦ **Summary of main findings.** The research highlighted that integrating UAVs into STEM educational activities generates a significant positive impact on student motivation, engagement in hands-on activities, and applied understanding of scientific and mathematical concepts. Qualitative and quantitative data analysis demonstrated that UAV-based activities stimulate student collaboration, develop critical thinking and creativity, and facilitate the acquisition of technical and digital skills necessary in the context of modern education.

♦ **Confirming the value of drones as STEM educational tools.** Empirical evidence confirms that drones are versatile and effective pedagogical tools that allow:

- interdisciplinary integration of mathematical, physical and technological contents;
- achievement of learning through project and direct experience;
- authentic assessment of skills through visible products (digital maps, 3D models, flight simulations);
- development of essential transversal skills for the 21st century, such as collaboration, autonomy and critical thinking.

**8. Recommendations for educational decision-makers and teachers**

For the effective and sustainable implementation of UAVs in STEM education, it is recommended:

♦ **Gradual integration of UAV modules into STEM curricula** – starting with extracurricular activities and optional modules, progressively until integration into the compulsory curriculum;

♦ **Continuing education of teachers** – developing the technical, pedagogical and interdisciplinary skills necessary for the effective use of drones;

♦ **Stimulating interdisciplinary collaboration** – creating joint projects between disciplines (mathematics, physics, computer science, environmental sciences) and between teachers, to maximize the educational potential of UAVs.

**9. Future research directions**

Based on the results obtained, future research may aim at:

♦ **Development of a virtual learning platform with UAVs,** which allows for flight simulation, data analysis and the implementation of educational projects independent of existing physical resources;

♦ **Implementing artificial intelligence (AI) in educational data analysis,** for monitoring student progress, personalizing learning paths, and optimizing teaching strategies.

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