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Aprendizaje STEM basado en diseño de aeronaves: una estrategia interdisciplinaria desarrollada para Clubes de Ciencia Colombia *

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RESUMEN

En este artículo se presenta una estrategia de aprendizaje STEM basada en diseño de aeronaves, con el objetivo de fomentar el desarrollo de la ciencia aeronáutica en Colombia. Esta estrategia de enseñanza fue desarrollada por instructores especializados del programa Clubes de Ciencia Colombia, buscando estimular en los jóvenes estudiantes colombianos su pasión por la ciencia, la tecnología y la innovación, y en el proceso, crear una red internacional de colaboraciones académicas. Fue utilizada la taxonomía de Bloom para clasificar y seleccionar tanto los objetivos educativos, así como el plan de enseñanza para el club de ciencias. Actividades STEM que alientan a los estudiantes a realizar experiencias de aprendizaje práctico que fueron la base de esta estructura de trabajo. Esencialmente, actividades interdisciplinarias relacionadas con la aeronáutica, la electrónica, las simulaciones computacionales y el dibujo técnico; caracterizaron este club de ciencias. Como resultado, los estudiantes pudieron diseñar, fabricar y probar su propio modelo aéreo lanzado a mano, aplicando todos los pasos del método científico: la concepción de ideas, el diseño y la ejecución de experimentos, y la comunicación de resultados. Después de las primeras pruebas de vuelo de los modelos aéreos, los estudiantes revelaron la capacidad de aplicar sus conocimientos de matemáticas junto con su aprendizaje de ciencias sobre las fuerzas de vuelo para mejorar su técnica de lanzamiento. Por lo tanto, fueron mejorados tanto el tiempo de vuelo como el alcance de los modelos aéreos. Finalmente, tanto estudiantes como instructores se beneficiaron a lo largo de la interacción de aprendizaje, ya que fue la primera vez que una comunidad rural es el escenario de un proceso de capacitación en ingeniería aeronáutica. Se espera que la divulgación de este material contribuya con la comunidad aeronáutica colombiana, ofreciendo perspectivas para nuevas propuestas de investigación y marcos de cooperación entre entidades gubernamentales y universidades.

PALABRAS CLAVE:

aprendizaje STEM, diseño de aeronaves, taxonomía de Bloom, aprendizaje práctico, método científico, Clubes de Ciencia Colombia.

Tecnologia e Inovação

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RESUMO

Neste artigo apresenta-se uma estratégia de aprendizado STEM baseada no projeto de aeronaves, a fim de incentivar o desenvolvimento da ciência aeronáutica na Colômbia. Essa estratégia de ensino foi desenvolvida por instrutores especializados do programa Clubes de Ciência Colômbia, buscando estimular nos jovens colombianos sua paixão pela ciência, tecnologia e inovação e, no processo, criar uma rede internacional de colaborações acadêmicas. A taxonomia de Bloom foi usada para classificar e selecionar tanto os objetivos educacionais, quanto o plano de ensino do clube de ciências. Atividades STEM que incentivam os alunos a realizar experiências de aprendizado prático foram a base desta estrutura de trabalho. Essencialmente, atividades interdisciplinares envolvendo aeronáutica, eletrônica, simulações computacionais e desenho técnico; caracterizaram este clube de ciências. Como resultado, os alunos foram capazes de projetar, fabricar e testar seu próprio modelo aéreo lançado à mão, aplicando todas as etapas do método científico: a concepção de ideias, o projeto e a execução de experimentos e a comunicação dos resultados. Após os primeiros testes de voo dos modelos aéreos, os alunos revelaram a capacidade de aplicar seus conhecimentos de matemática em conjunto com o aprendizado de ciências nas forças de voo, a fim de melhorar sua técnica de lançamento. Assim, foram aprimorados tanto o tempo de voo quanto o alcance dos modelos. Finalmente, alunos e instrutores foram beneficiados durante toda a interação de aprendizagem, pois foi a primeira vez que uma comunidade rural é cenário de um processo de formação em engenharia aeronáutica. Espera-se que a divulgação deste material contribua à comunidade aeronáutica colombiana, oferecendo perspectivas para novas propostas de pesquisa e estruturas de cooperação entre entidades governamentais e universidades.

PALAVRAS-CHAVE:

aprendizado STEM, projeto de aeronaves, taxonomia de Bloom, aprendizado prático, método científico, Clubes de Ciência Colômbia.

Technology and Innovation

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ABSTRACT

This article describes a STEM learning strategy based on aircraft design in order to promote the development of aeronautical science in Colombia. This teaching strategy was developed by specialized instructors from the Science Clubs Colombia program, seeking to stimulate in young Colombian students their passion for science, technology, and innovation, and in the process, create an international network of academic collaborations. Bloom's taxonomy was used to classify and select both the educational objectives, as well as the teaching plan of the science club. STEM activities that encourage students to perform hands-on learning experiences were the basis of this framework. Essentially, interdisciplinary activities involving aeronautics, electronics, computational simulations, and technical drawing; characterized this science club. As a result, the students were able to design, manufacture and test their own hand-launched air-model, applying all steps of the scientific method: the conception of ideas, design, execution of experiments, and communication of results. After the first flight tests of the air-models, the students disclosed an ability to apply their mathematics knowledge in conjunction with their science learning on the forces of flight, in order to improve their launching technique. Therefore, both the time and range of the air-models were enhanced. Finally, both students and instructors benefited throughout the learning interaction, since it was the first time that a rural community is the scenario of an aeronautical engineering training process. It is expected that the dissemination of this material will contribute to the Colombian aeronautical community, giving outlooks for new research proposals and cooperation frameworks between government entities and universities.

KEY WORDS:

STEM Learning, Aircraft Design, Bloom's Taxonomy, Hands-on Learning, Scientific Method, Science Clubs Colombia.

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INTRODUCTION

Historically, the countries most involved in the development of the aeronautical sector in Latin America have been Brazil and Colombia. The Brazilian inventor and engineer, Alberto Santos Dumont (July 20, 1873 - July 23, 1932), is recognized by the scientific community as one of the most important pioneers of aviation (Torenbeek and Wittenberg, 2009). Among his projects is highlighted the SD19 (Demoiselle) aircraft, whose 10.2 m^2 of wing area, 120 *kg* of maximum takeoff weight (MTOW) and 24 horse-power (HP), make it the precursor of modern aircraft, creating the design principles of both, light aircraft and general aviation (Abdalla and Catalano, 2013; Ibrahim and Mohnot, 2006).

On the other hand, the title of precursor and creator of the aviation in Colombia is awarded to Gonzalo Mejía (Medellín, 1884 - 1956), whose proposal to use amphibious aircraft for passenger and cargo transport missions along the Magdalena river aroused great interest in promoting the aviation in Colombia (León, 2011). Thus, in 1921, the CCNA (Compañía Colombiana de Navegación Aérea) and the SCADTA (Sociedad Colombo-Alemana de Transportes Aéreos) were founded in Medellin and Barranquilla, respectively.

After years of evolution and development due to the end of the Second World War, Brazil and Colombia began to manufacture aircraft at the end of the 60s, just after the creation of the Andean Pact. In Colombia, Aviones de Colombia S.A company quickly embarked on this project, expanding the aircraft market in Venezuela, Chile, Peru, and Bolivia. This led to the Colombian assembly system became the first in the world in its sort (Corradine, 1980). Something similar happened in Brazil, where Embraer S.A company besides manufacturing Piper aircraft, also designed their aircraft, which began to be certified due to bilateral agreements with the United States (Dinero, 2000). It should be noted that the importance of such efforts qualified to Embraer as one of the most important companies in the aeronautical sector (3rd biggest aircraft manufacturer in the world)(Forjaz, 2005).

Although both countries began their aeronautical industries at the same time, there are several crucial aspects that finally marked the current situation of the Colombian aviation. For example, Brazil greatly enhanced its air power, not only because of the size of its aeronautical infrastructure, but also because of its ability to generate technology, research, and, above all, employment (Bernardes, 2000). Furthermore, the stability of policies and the scientific projects developed between Brazilian Universities and Embraer led to this company to success, i.e., Brazil managed to synchronize economically several political and scientific aspects with Embraer (Catalano, 2018; Catalano and Carmo, 2013; Suzigan and Da Motta, 2011).

Based on the remarkable characteristics described above, perhaps the most important difference between Brazil and Colombia is the structuring of policies that the aeronautical authority of each country have established. Therefore, according to this literature review, the most viable way to improve the aircraft development in Colombia is the agreement of the efforts of the State, the academic community and private entities, to combine the political, scientific and economic aspects, respectively (Guzmán, 2006).

It is worth mentioning that during the last years, the aeronautical sector in Colombia has undergone essential changes. The creation of CIAC S.A (Corporación de la Industria Aeronáutica de Colombia) is one of the great achievements of the Colombian government. Outstanding projects are being developed in this unit, standing out the Calima T-90, the Urubu S-17 glider, and Unmanned Aerial Vehicles (UAVs), such as the UAV Quimbaya and UAV Coelum, which encourage the design and manufacture of aircraft in Colombia, expanding the aerospace industry due to the participation of military and civil companies (Aeronaves no tripuladas, 2019; Aeronaves tripuladas, 2019; UAV Coelum, 2019).

On the other hand, it is also important to mention some of the university projects that have been highlighted in Colombia. For example, Betancourth et al. (2016) designed and manufactured the first Colombian solar-powered UAV, called UAV-SOLVENDUS. Bravo-Mosquera et al. (2017) created a hybrid UAV to carry out superficial missions of volcanic environments, called URCUNINA-UAV. It should be noted that both aircrafts mentioned above were developed by engineers of the Fundación Universitaria Los Libertadores in cooperation with the São Carlos School of Engineering - University of São Paulo. In addition, Escobar (2011) presented the Navigator X-2 project, whose primary mission is the civilian surveillance of the Colombian territory. This UAV belongs to the Universidad San Buenaventura. Gutiérrez, Hazbón, and Appel (2012) reported several UAVs designed by engineers of the Universidad Pontifícia Bolivariana for operating in the Colombian mountain environment. Finally, Rocha and Solaque (2013) described the conceptual design of a UAV to perform exploration missions in Colombia, which was proposed by the Universidad Militar Nueva Granada.

Considering the designs above, note that important advances can be achieved if science is linked to industry and research programs. For this reason, in this article is proposed a training and project-based pedagogical approach in the aircraft design discipline. Our primary interest is to promote aeronautical engineering to all students who admire the flight of an aircraft and seek to acquire knowledge in this science. This objective was accomplished by proposing a STEM (Science, Technology, Engineering, Mathematics) learning strategy using mainly hands-on activities, which aims to eliminate the classic teaching practices, and demonstrate that students learn best when learning is active, i.e., when they are engaged in hands-on classroom activities, and involved in what they are learning. It should be noted that Bloom's taxonomy was used to structure curriculum learning objectives, assessments, and activities. Thus, the proposed STEM learning strategy involved both free computational tools that provide an interdisciplinary work environment and also simple and inexpensive materials for aircraft manufacturing.

Besides offering an experience closer to professional activity, this teaching-learning process provides an adequate understanding of the involved subjects. The authors implemented the proposed method during the Science Clubs Colombia (Clubes de Ciencia Colombia) week and the positive results inspired to keep it on the curriculum.

After this introduction section concerning the history and the current design trends of the aeronautical sector in Colombia, section "Background" presents the state-of-the-art of current learning strategies and its application to aerospace engineering problems. Section "Application of STEM Learning Strategy" provides the methodologies used to develop the STEM learning strategy and the hands-on activities. Section "Science club – Aircraft design" presents the application of the STEM learning strategy and the contents of the activities developed in each day of the science club. Section "Results" describe the main results obtained during the execution of the science club – aircraft design. Finally, the section "Conclusions" sums up the main contributions of the article.

BACKGROUND

Usually, understanding how airplanes fly is the childhood desire of most of the aeronautical community. We use that initial motivation to develop a learning strategy based on STEM education for young learners, introducing real-problem design practices, and considering that students have not engineering experience.

STEM education has been evolving from a set of overlapping disciplines to a more joined and interdisciplinary approach (Bybee, 2010a). This new learning methodology includes the teaching of academic concepts through real-world applications and combines formal and informal learning in schools, the community, and the workplace (Bybee, 2010b). In this way, STEM learning seeks to impart skills such as critical thinking and problem solving, along with soft skills such as cooperation and adaptability (Drew, 2011). For this reason, basic STEM concepts are best learned at an early age (in elementary and secondary school) because they are the essential prerequisites to career technical training, to advanced college-level and graduate studies (Trilling and Fadel, 2009; Conley, 1997).

Teaching aerodynamics is an excellent pedagogical opportunity to awaken the reminiscent knowledge that is on the natural curiosity of children. Example of this approach can be seen in many aeronautical and mechanical engineering schools, where teachers motivate students in activities that develop curiosity and creativity such as airplane building competition (Catalano et al., 2012). In fact, there are some frameworks that were the basis for the development and execution of this educational strategy. For example, Catalano et al. (2012) reported an educational strategy for better prepare newly graduated engineers for the global era. In this article, the authors developed an innovative approach to current engineering education that utilizes traditional design-centric methodologies, adding new disciplines to supplement traditional engineering education. The positive feedback received from the industry, in general, demonstrate that the proposed method enhanced the design capabilities of the engineers that acquired this course. Agrico de Paula et al. (2013; 2015a; 2015b; 2016) reported several study cases about interdisciplinary experiences in aeronautical engineering education. The authors described the interdisciplinary activities as integration processes that engage educators and learners in joint work, i.e. the interaction of school curriculum subjects with each other and with real-world problems, overcome the fragmentation of traditional teaching. For that reason, particular modifications in the curriculum of the aeronautical engineering program of the Instituto Tecnológico de Aeronáutica (ITA) were adjusted. For example, before 2014, the subjects of metrology and technical drawing were assumed in a traditional teaching way, i.e. without the correlation of both courses and a practical view about the relevance of these courses for future engineers. However, after 2014, the Physics department at ITA developed a new teaching-learning process, connecting several interdisciplinary knowledge through a practical view. As a result, students of the early courses of aeronautical engineering assembled air-models successfully, given the great interest of students in aeronautical design. A similar conclusion was presented by Passador et al. (2017), however, as this method has already been applied over the last years at ITA, currently, the project has the direct involvement of teachers of the aforementioned subjects, laboratory technicians and monitors.

Another example concerning going hands-on in STEM issues involved active learning for mechatronics labs (Ramírez-Cadena et al., 2008). In this article, the authors integrated industrial technologies, hands-on activities, and laboratory equipment's to improve communication between teachers and students by developing robots for different applications. As a result, students noticed how to deal with situations that may arise by multidisciplinary working teams to face problems in industrial environments. On the other hand, Alba and Orrego (2013) intended to identify methodological strategies to inspire graduate students to use virtual tools in their professional preparation. After testing many strategies, the authors concluded that educational experiences based on learning by doing practices are the key to the achievement of the proper use of technological tools. Finally, English and King (2015) reported a STEM learning strategy for fourth-grade students' investigations in aerospace. In this article, the authors developed a basic pedagogical strategy involving the design of paper air-models that were constructed, tested and redesigned. The main conclusion from this study was that well-structured engineering experiences provide opportunities for students to engage in the design process of an aerospace problem.

Based on the previous description about educational strategies in an engineering context, it is possible to infer that STEM education at the pre-college levels is obtaining increased international significance. It is evident that the traditional teaching process in engineering has changed. For this reason, the new educational methods based on STEM learning and learning by doing (hands-on), provide a cohesive learning paradigm based on real-world applications. Thus, the key to this STEM learning strategy was to involve several interdisciplinary knowledge through a practical view.

Fundamentals of aircraft design, addressing the principles of aeronautics and electronics were the primary basis of this science club. Likewise, computational simulations and technical drawing tools were integrated into an interdisciplinary approach to consolidate the knowledge learned during the theoretical foundation. This allowed students to get involved in a purely practical environment, in which students' engagement with each of the framework's design processes revealed problem scoping components in their initial designs and flight tests. As instructors, we are sure that the dissemination of this material can serve to enrich the educational environment in four specific disciplines: science, technology, engineering, and mathematics. Figure 1 shows the outline of the STEM learning strategy of the proposed exercises. Note that students manufactured and tested an air-model using the knowledge from the theoretical foundation, hands-on practices and the interdisciplinarity between them.

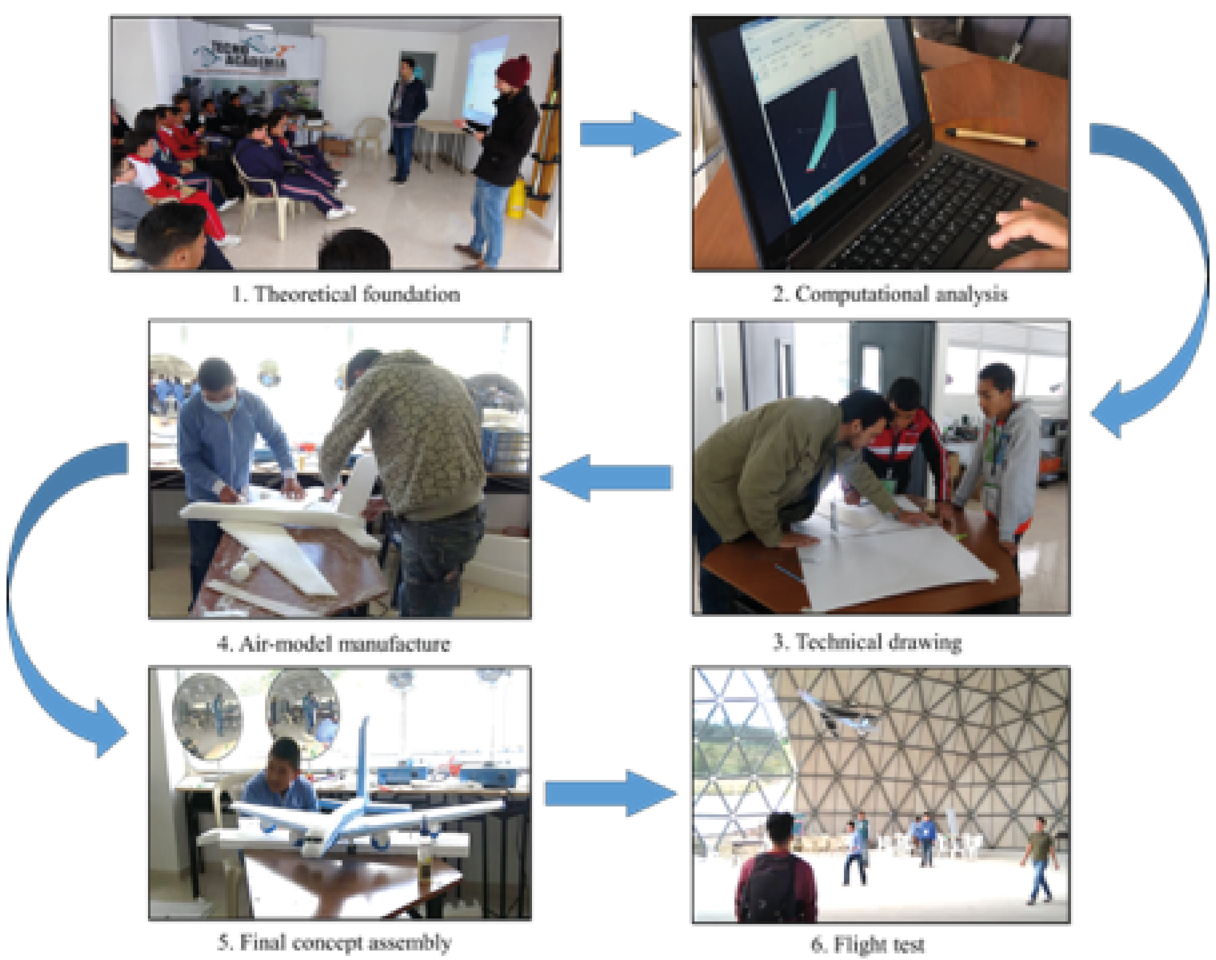

Figure 1. The interdisciplinary framework developed for the science club – aircraft design.

APPLICATION OF STEM LEARNING STRATEGY

Bloom's taxonomy was implemented in order to develop and select the optimal teaching plan of the science club. It includes the recognition of specific facts such as procedural patterns and concepts that serve in the development of intellectual abilities and skills (Ferraz and Belhot, 2010). Currently, teaching has been focused on the lowest levels of education, i.e., those that do not care to reach a significant level of learning, such as listening, memorizing and understanding. However, as move up the hierarchical levels of Bloom's taxonomy, we find goals that are much more meaningful for student learning, such as analyzing, evaluating, and creating. Many of these implicit objectives are related to cognitive aspects of high abstraction, such as STEM classes, where students must learn to think critically as they use science, technology, engineering, and mathematics to solve real-world problems (Drew, 2011).

According to Bybee (2010b), the verbs taken from STEM lesson strategies hint at the possibilities:

- Science – Evolve, recycle, verify, interpret, recognize.
- Technology – Create, build, design, plan.
- Engineering – Construct, simulate, assemble, invent, experiment
- Mathematics – Solve, investigate, prioritize, justify, analyze

As STEM learning comprises activities that involve skills in analysis and synthesis; all learning is hands-on (Christensen, Knezek, and Tyler-Wood, 2015). Therefore, through Bloom's taxonomy, a STEM learning strategy was developed to successfully complete these objectives. In conclusion, Bloom's taxonomy provides students with preparatory learning for the future, which is the primary goal of education. The teaching plan along the 6 days of activities, including our version of Bloom's Taxonomy, selected subjects, cognitive domain, educational strategies, instructional techniques, and classroom tasks is shown in Table 1. This educational strategy is divided into four major modules (see Figure 2), which were developed based on the strategies for effective training and education in information technology (Glennan and Melmed, 1996).

This STEM method applies Active Learning (AL) techniques such as collaborative learning and self-learning. In addition, it uses technological resources to enrich and make more efficient the learning process. AL techniques are widely used in laboratory classes as they enable students to learn by doing (hands-on). In this context, the students are actively working with laboratory equipment and interacting with their classmates. The main idea is that students develop, besides knowledge, abilities such as self-learning, critical thinking, creativity, teamwork, effective communication skills, leadership, among others (Ramírez-Cadena et al., 2008).

TABLE 1.

Teaching plan of the science club – aircraft design.

DAY	OBJECTIVES	SUBJECT	COGNITIVE DOMAIN	EDUCATIONAL STRATEGY	INSTRUCTIONAL TECHNIQUES	CLASSROOM TASKS
1	Recognize	Scientific method	Understanding	Exploratory	Photos and videos	Discussion
	Interpret	History of aviation	Synthesis	Exploratory	Photos and videos	Discussion
	Interpret	Components and acting forces on an aircraft	Analyzing	Exploratory	Photos and videos	Without task
	Experiment	Bernoulli's principle and Newton's third law	Applying	Support and training	Physics laboratory	Individual task
2	Recognize	Aircraft performance	Understanding	Exploratory	Photos and videos	Without task
	Create	Paper airplanes	Applying	Exploratory	Folding instructions	Individual task
	Simulate	Aircraft aerodynamics using XFLR5 (free software)	Applying	Support and training	Computing laboratory	Laboratory tests
	Design	Air-model three-view design	Applying	Support and training	Technical drawing	Teamwork
3	Interpret	Basic electronic concepts	Understanding	Exploratory	Photos and videos	Without task
	Interpret	Basic navigation light system	Synthesis	Exploratory	Photos and videos	Discussion
	Assemble	Electronic circuit on a breadboard	Applying	Support and training	Electronics laboratory	Teamwork
4	Construct	Hot wire cutter for polystyrene	Applying	Support and training	Electronics laboratory	Teamwork
	Construct	Air-model	Applying	Support and training	Physics laboratory	Teamwork
	Assemble	Navigation light circuit on air-model	Applying	Support and training	Electronics laboratory	Teamwork
5	Verify	Entire assembly of the air-model	Synthesis	Exploratory	Folding instructions	Teamwork
	Plan	Flight test	Assessing	Support and training	Folding instructions	Teamwork
	Analyze	Flight time of the air-model	Assessing	Support and training	Folding instructions	Discussion
	Draft	Poster of the science fair	Applying	Support and training	Folding instructions	Teamwork
6	Exhibit	Main results and experience	Synthesis	Dialogic	Slides	Presentation

Thus, all classroom sessions were designed to let students take control of the equipment, performing activities such as operation, judgment, improvements, and implement real-world projects. As indicated in Fig. 2, we consider the application of STEM knowledge during the design process of the air-models. This framework served as a reference point for developing the classroom activities, enabling the identification and analysis of the students' developments, particularly concerning their group and class discussions.

PROBLEM DEFINITION.	CONCEPTION OF IDEAS.	DESIGN AND MANUFACTURE.	DESIGN EVALUATION.
• Provide specific introductory training.	• Provide experiences and advanced training.	• Air-model development (hands-on activities.	• Meeting design restrictions.
• Explain and reaffirm the goal. • Identify design restrictions. • Consider problem feasibility. • Perform experiments. • Establish teamwork.	• Share experiences. • Discuss strategies. • Develop a plan.	• Sketch the initial design. • Performs simulations. • Interpret flight characteristics. • Transform design to air-model.	• Test air-model. • Check design restrictions. • Verify flight quality. • Final flight test.
STEM learning strategy (Science Clubs Colombia – Aircraft design)			

Figure 2. Science club – aircraft design, STEM learning strategy.

Problem definition

During the problem definition, rapid and well-structured classroom sessions were provided by the instructors in order to introduce students to the aeronautical field. As the main goal of the science club – aircraft design, was to design, manufacture and flight test of an air-model, the understanding of aerodynamic concepts such as angle of attack, boundary layer, Reynolds number, stall behavior, tip-vortices and its relation with aerodynamic design, provided students the necessary knowledge to the execution of their activities. It is worth noting that all activities followed the scientific method framework in order to provide students the ability to solve problems, perform experiments, and present results.

Once identified the main objective of the entire course, students recognized the design restrictions/requirements that were given by the instructors. These restrictions included: time of execution, air-model dimensions, quantity and quality of materials, manufacture tools, etc. Thus, students explored, evaluated, and discussed the design constraints. The generation of design ideas that must match design constraints involved students in real engineering situations, allowing them to identify and recognize problems to figure out solutions. Finally, before starting with the air-model design and execution, several individuals and group activities were performed to carry out experiments of the most important subjects presented. Those activities allowed to identify, among others, how to promote cooperation between team members, and who will assume the leadership of the team.

Conception of ideas

The main objective of the conception of ideas was to enable students to share and formulate thoughts about the possible strategies for designing the air-models. The active participation of the team members was an essential element to develop an in-depth understanding of solution processes and key features. For this reason, as instructors, sharing our own experiences of real problems, challenged students to perform interesting concepts.

Design and manufacture

This process required the development of skills to analyze problems, propose solutions, and prepare a collaborative plan to face real and complex situations. Several hands-on activities to simulate problems during the design of the air-models, such as computational simulations and technical sketches, allowed to improve proactivity and originality. Therefore, the aerodynamic theory provided by the instructors offered freedom to select airfoils, select tail configuration, and design wings. In this way, students interpreted the flight characteristics of their air-models. Through their initial drafts, students created new ideas, developed theoretical STEM knowledge, and transformed their sketches into 3D models.

Design evaluation

As noted in Figure 2, the last stage of this STEM learning strategy intended to achieve the design constraints of the air-model development. During this stage, students applied their STEM knowledge to perform flight tests of their air-models and compete with the designs of their classmates. The students discussed in their groups how and why they could modify both their launch strategy and their designs to win the building/flying competition elaborated by the instructors. During the first flight attempt, the students recorded the flying time, the path in flight, and how the air-models landed. Thus, during the second flight attempt, the students applied their learning about flight forces to improve the flight quality of their air-models. Most students were able to suggest ways to improve their first flight attempt. Their proposed improvements featured a range of changes including altering the gravity center the plane, adding flaps at the back of the wings, increasing the plane speed, among others. To conclude, final discussions summarized the entire science club, and surveys were performed to know students' opinion about the course.

SCIENCE CLUB – AIRCRAFT DESIGN

Science Clubs Colombia (Clubes de Ciencia Colombia) is a Latin American STEM education initiative whose mission is to expand scientific education to youth and children in Colombia. The initiative born in 2015 with some Ph.D. and Masters Students from Boston, Massachusetts at Harvard University and Massachusetts Institute of Technology MIT who participated in Science Clubs Mexico, and they wanted to expand this idea to Colombia (Mcb, 2016). Science Clubs is a one-week camp conducted by Colombian scientists who are studying or working abroad and want to bring inspiration for young people in Colombia. This idea arose to bring science to rural areas in Colombia, expanding scientific education from cities to rural zones, aiming to inspire the next generation of scientists in the region.

The idea behind to bring the scientists is to involve them into a scientific revolution: make science and technology a priority for people. That is why youth and children are relevant for this ideal. More than 5 years, 6000+ children and young people impacted, more than 600 scientists (national and international) and 300 alliances with national and international institutions are just some numbers inside the initiative (Avendaño-Uribe, 2018).

Thanks to the alliances and cooperative institutions, science clubs developed a short course and content about aerodynamics and aircraft design, in which students design their 3D animation and build their air-model with the instruction of an international and a national scientist. A short 3-week training on pedagogical schemes and approach about how to make a club, allow the instructors to create the course and create a curriculum for each day.

The STEM learning strategy of the science club – aircraft design, involved 20 students from secondary school, where five teams were created. This course was offered at the headquarters of the Tuquerres – Nariño city, specifically in the facilities of the TECNOACADEMIA – SENA. The groups were organized as a typical aerodynamic team in aeronautical industry (Catalano et al., 2012). The entire course was taught in one week, including the science fair where the students presented and explained how their air-models were designed. Each day comprises several subjects that led students to consolidate the following items:

- Consolidate knowledge on the multidisciplinary viewpoint.
- Stimulate creativity.
- Teamwork.
- Learn to learn.

In this context, each day had a mainstream of subjects, being strictly introductory disciplines in the engineering area. The classes were taught using photos and videos as instructional techniques; however, hands-on activities composed most of the classes.

As instructors, we had the objective of preparing the students for expository and laboratory classes. The design process of the air-models was split into five phases (five days), so that each of which is supported by a theoretical explanation in terms of aeronautical and pedagogical approaches:

Day 1 – Introduction to aeronautics

The science club - aircraft design started by recognizing the primary meaning of the scientific method. After this explanation including some examples of aerodynamics, students had the possibility to ask and answer scientific questions by making their own inquiry, and considering the six steps of the scientific method, which are: ask a question, perform a state-of-the-art of similar researches, construct a hypothesis, perform simulations and experiments, analyze data and finally, report the results obtained (Cohen, 2013). Some interesting examples created by the students were: How a wind turbine converts wind energy to electrical energy? Which is the function of the wings on an aircraft? These questions allowed to conclude that students understood the particular concept. In fact, students successfully completed the six steps of the scientific method throughout the science club week, since they acquired knowledge about aeronautics, to develop and show up their own air-models.

Once explained the scientific method, the introductory course of aeronautics took place, starting with a brief discussion about the history of aviation. This subject was crucial because the students learned some specific terms of the aeronautical nomenclature, such as the definition and classification of aircraft. The presentations included photos and videos about the evolution of the aeronautics. Along the lecture of the history of aviation, students interpreted and knew the layouts of the aerodynamic concepts from the pioneer era, until the current aerospace age (Crouch, 2004). The main conclusion of this session was to clarify that despite the growing problems faced by aviation, future aircraft will offer unique capabilities in terms of speed and payload. Therefore, as long as people have transportation requirements, aviation will always be necessary.

The second subject of this introductory day was the description of the components and acting forces on an aircraft. The explanation of this discipline was perhaps the most challenging part of the science club, due to the vast aeronautical nomenclature involved. However, the use of photos and videos aided on the interpretation of the involved concepts, by making a relation between the parts of the aircraft and their function on the acting flight forces. In sum, the students interpreted the flight of an aircraft in a straight-and-level unaccelerated condition. Figure 3 shows a schematic of the acting forces on an aircraft.

The interpretation of these forces regarding their function and controllability was essential to the progress of the air-models developed by the students. For example, explaining the lift force, some concepts such as the angle of attack, wing surface, relative velocity, lift coefficient, among others, were the basis for understanding that the aircraft wing must generate enough lift to overcome the aircraft weight. The description of the lift force cannot be well understood without the explanation of the drag force. Therefore, some concepts such as wetted area, parasite drag, induced drag, aspect ratio, among others, expanded the information previously provided. Finally, basic concepts about the propulsion system and its relation to the thrust force were provided (Anderson, 2000). The above basic aerodynamic theory gives to the student's freedom to design airfoils, wings, empennage, and fuselage; providing also support to develop analytical thinking. Finally, to conclude the first day of activities, some experiments of the Bernoulli's principle and Newton's third law were carried out to understand how the aircraft forces are generated.

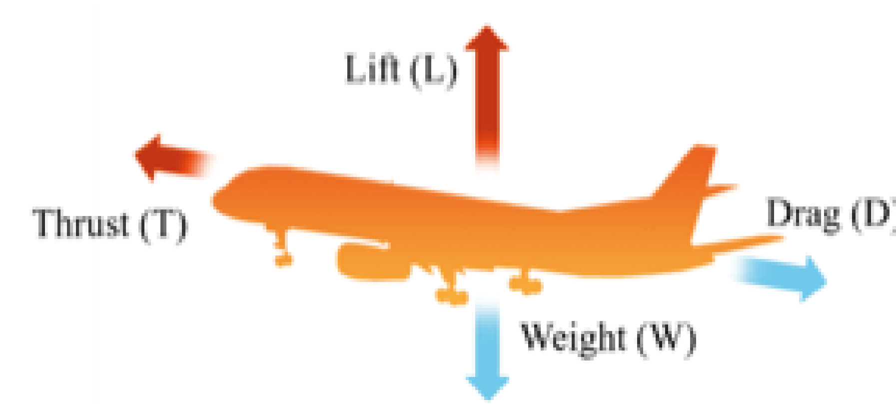

Figure 3. Acting forces on an aircraft. Available from: https://sites.google.com/site/mrjimismypsciencesite/myp2/physics-2/08-force-diagrams

Day 2 – Computational model and technical drawing

The second day started with a brief lecture about aircraft performance and dynamic activity to create paper airplanes. A single A4 sheet of paper was used for this purpose. The aim of this step was to reinforce the knowledge learned the previous day. Subsequently, hands-on activities by performing computational modeling were conducted using the XFLR5 free software (Deperrois, 2010). This tool allows simulating the aerodynamic characteristics of several airfoils and 3D configurations using the vortex lattice method. Therefore, students generated and simulated a 3D perspective of their air-models to study the flow patterns around their models. Some aerodynamic characteristics that students could appreciate through this program were: pressure contours, streamlines, lift distribution, wingtip vortices, among others.

Activities started by performing two-dimensional simulations of several airfoils used in aero-modeling activities. Then, as students already know the main flight principles, they selected the best airfoil in terms of aerodynamic efficiency to be used in their wing designs.

The simulation of the aerodynamic environment was essential to learn how to consider direct (aerodynamics) and indirect (weight, loads, structural) variables to make decisions, i.e. simulate, compare and modify several aspects during the design development, such as Reynolds number, angle of attack, flight altitude among others, was relevant to improve proactivity and creativity. Figure 4 shows students creating their own design in the XFLR5 software.

Figure 4. Computational modeling of one of the groups using XFLR5 free software.

To conclude this day, a session of technical drawing was conducted in order to compose drawings that visually communicate how the air-models were constructed. At this point, the classroom was arranged to take place discussions, giving to the student's opportunity to create, encourage team working, and propose design alternatives of the air-models. Some rules of thumb were given by the instructors, such as the size of the horizontal and vertical empennage as a function of both, the wing surface and the distance between the aerodynamic center of the wing, and the aerodynamic center of the horizontal tail. In this way, students sketched the air-model three views to realize specification needs during the build process. Figure 5 shows the beginning of the air-model drawing.

Day 3 – Introduction to Electronics

The third day was dedicated exclusively to teach the main basis of electronics, to develop a basic circuit of a light navigation system. To reach this objective, the instructors started to explain the basics of the electricity phenomenon, from the empirical experiments of the Greeks to the latest advances in electronics and its future. Then, more attention was given to the aeronautical field, with the aim of understanding the basic light navigation system of an aircraft. Figure 6 shows the basic scheme of the light navigation system, which indicates the relative position of the aircraft concerning other aircraft and helps to identify the position and direction of flight from the ground perspective.

Figure 5. The first step of the technical drawing of the air-models.

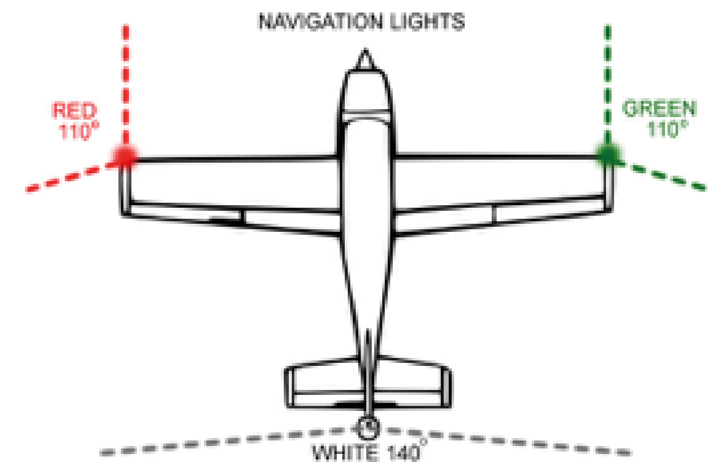

Figure 6. Aircraft position/navigation lights. Available from: https://learntofly.ca/aircraft-navigation-lights/

Students received folding instructions to develop the proposed electronic circuit. They could identify and understand the main components of the circuit, its respective function, and connections. In this way, it was possible to reinforce more theoretical concepts through practice, such as electrical circuit, resistance, conductivity, capacitance, and inductance. Figures 7 and 8 sum up the activities performed by students. Note that Figure 7 shows the proposed electronic circuit, while Fig. 8 shows its respective scheme of connections.

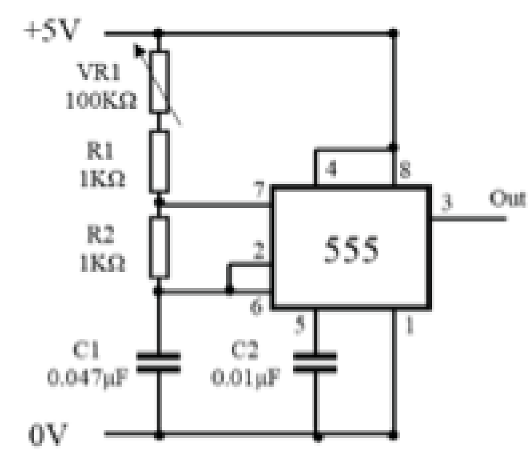

Figure 7. Basic light navigation system – electronic circuit.

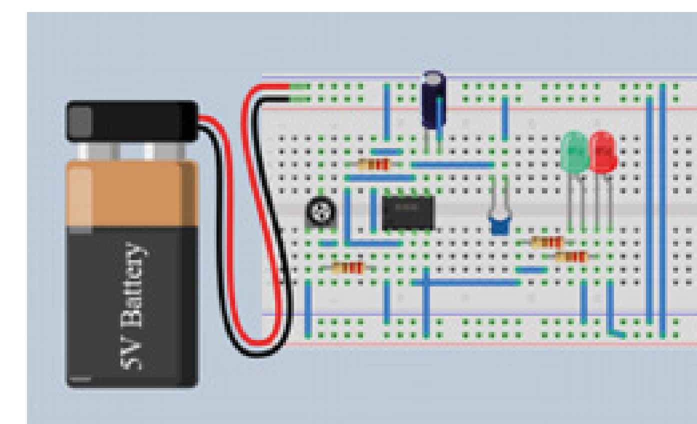

Figure 8. Scheme of connections.

Day 4 – Air-model manufacturing

In this day, students dedicated exclusively to the handcraft air-models manufacturing. The air-models assembly was made in a small physics laboratory, where students had the first real contact with the materials and tools required in the manufacturing process.

Each group used a polystyrene sheet of 1m x 1m x 0.5m for the entire design. First of all, students had to build their hot wire cutter of polystyrene to facilitate the cutting process of the aerodynamic surfaces. As the three views of the air-models were previously drawn on A0 paper sheet, students only had to trace those drawings on the polystyrene sheets. Also, the selected airfoils by each group were printed on the appropriate scale, to guide the aerodynamic form of the wing. This technique allowed to obtain well-defined aerodynamic shapes.

After the students' work during the manufacturing process of the air-models, instructors conducted a discussion about the main characteristics of the designed models. This discussion was necessary to reinforce the knowledge learned in the previous days, to aid students to prepare the flight test of their models. Finally, students could paint and named their air-models as a recreational activity to treasure their effort during the learning process. Figure 9 records the active participation of the students to manufacture their own designs.

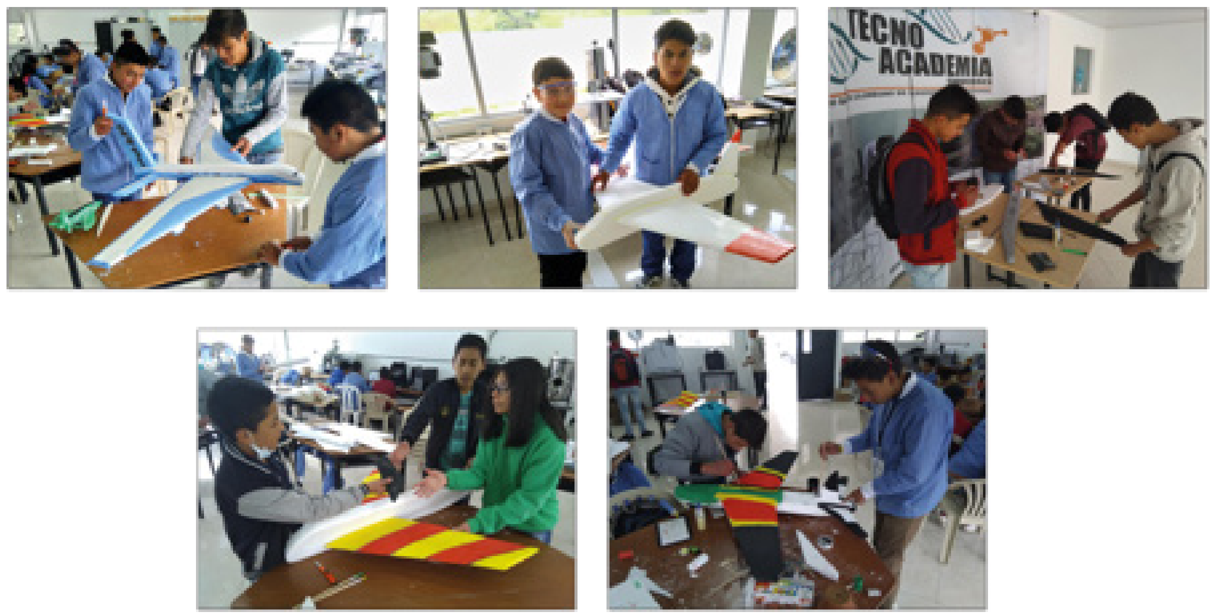

Figure 9. Photographic record of all the participating groups of the science club – aircraft design.

Day 5 – Air-model assembly and flight test

When the assembly of all aerodynamic surfaces concluded, the electronic circuit of the light navigation system was mounted on the air-models. Then, the gravity center of each model was verified by the instructors to perform a flight in a unique trim condition, showing the concept of equilibrium in flight dynamics. These flight tests served to apply information at the real situation, relating theory and practice. Make students get involved in a real flight situation allowed them to identify and recognize problems to figure out solutions.

Day 6 – Science Fair

As explained above, students presented their results in a science fair developed the last day of the science club week. It was an exciting opportunity to share their experiences by describing the compiled data and explaining their main results. The way in which students reported their results were in a printed poster, which was designed by one member of each group. A copy of this poster is showed in Fig. 10. It should be noted that the poster was written in Spanish language.

RESULTS

The learning strategy applied in the science club – aircraft design, provided to students the opportunity to develop some skills that are not practiced in traditional education, mainly due to hands-on activities. During this week, instructors and students realized an improvement in some skills such as creativity to solve problems and critical thinking to make decisions. The main results of this paper are described as follows:

3D simulation and the goal of building their own aircraft model, allowed students to get involved in more physics and academic content that help them to understand principles and concepts about aerodynamics.

One-week intensive inspirational classes followed by a showcase in a science fair for the rural community, motivated children to work hard and constant for obtaining results about their models and creations.

Figure 10. Poster created by the students of the science club – aircraft design.

The 80% hands-on experience combined with 20% theoretical content, showed up the inspiration of children from the beginning, which is the main objective of the Science Club Colombia program. The first flight attempt of the air-models showed problems concerning flight stability. However, we realized that students applied their knowledge about mathematics and science to improve the flight quality of the first flight attempt. New calculations of the gravity center position, wing surface increase by adding flaps, speed increase, modifications of the tail position are just some of the modifications performed by the students.

Students by themselves noted that some air-models had difficulties in performing a straight and level flight. However, after several attempts, air-models registered an average time of 15 seconds in flight, reaching a distance of approximately 28 meters. These values represent very satisfactory results due to the intensity of the course and the short time of instruction.

At the end of the week, the camp became a unique experience for both groups: children and scientists. Everybody in the small town talked about science and technology. Children were inspired by the hands-on experience to think about a possible future STEM career. It is important to highlight that two girls attended the science club, and one of them would like to continue an aeronautical career, as a possible professional opportunity for women in this industry.

Scientists were inspired by the experience of sharing their knowledge and build together the course because they learned about how to teach some high-level concepts in aerodynamics and how to explain it to children who need it for their next step: building a handcraft air-model. It is worth clarifying that the instructors obtained the best qualification from the students in relation to the teaching techniques used.

The rural community became inspired by the entire experience because it was the first time in Tuquerres, Nariño - Colombia that aeronautical and electronic engineers came to visit and explore the potential of this technology in this town with the children.

To conclude, Figure 11 shows all the participants of the science club – aircraft design, including the five air-models designed.

Figure 11. Complete group of students who participated in the science club – aircraft design (showing up their air-models).

CONCLUSIONS

This paper describes a STEM learning strategy in aeronautical education, which was developed for the participant students of the science club 2018 in Tuquerres - Nariño. The main objective of this science club was to expand access to high-quality science education in aeronautical engineering, inspiring and mentoring the future generation of scientists through international scientific networks. Our study has provided an example of how young students can participate in processes of engineering design and apply interdisciplinary knowledge to solve interesting problems. Based on this research, the following conclusions and limitations are drawn:

Throughout this article, authors highlighted the importance of teaching engineering using interdisciplinary approaches that establish relations among several disciplines, which is appropriate in the aeronautical engineering context. In this sense, it is clear that the proposed methodology was indispensable to consolidate the presented concepts.

Despite the short time of the course, intensive and hands-on experiences browsed into aeronautical principles to consolidate and build in three days a handcraft air-model. Also, the use of free software tools, with user-friendly interfaces, helped students to develop some skills like creation and teamwork.

This study was confined to classrooms in just one consolidated group. Therefore, it is necessary to implement this science club in other groups, to take this paper as a reference, and then, to compare students' behavior and acceptability concerning the course.

It is essential to continue with the learning process after the science club – aircraft design to encourage students to continue research in science and engineering. In this case, the existence of research, support, and technological management instruments, committed to the permanent generation of knowledge, may create culture training and aeronautical know-how.

It is expected that the dissemination of this material will contribute not only to the Colombian aeronautical community but also to all teachers who teach science during the first years of the school.

Finally, an in-deep knowledge about aircraft design could be implemented, aiming to expand this course to the first semesters of the aeronautical engineering career, giving to students and teachers both, a research perspective of the aeronautical field and support for new research proposals and cooperation frameworks between government entities and universities.

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