An Experiment- and Project-based Learning Approach to Increase Interest of High School Students for STEM and Enhance Soft Skills of STEM Students

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***Abstract*—This innovative practice work-in-progress paper presents a combined approach of experiment-based and project-based learning. The motivation and potential benefits are described. Initial experiments are outlined and the positive feedback from the STEM students is shown. The outcome of this approach will be evaluated via student questionnaires before and after participation. A short overview of potential future advancements of the chosen approach is given. The developed experiments can be included in the DLR_School_Lab network, exhibited for internal training purposes or at public events. In conclusion, this very approach could contribute to an improved social acceptance for innovative technologies and an increased interest of high school students in STEM courses, while preparing STEM university students for leadership roles.**

Keywords*— *project-based learning, interest in STEM, soft skills, career guidance, clean aviation

I. Introduction

Innovative technological solutions are necessary to limit climate change and its consequences. This applies to aviation in particular. Here, electrification of the propulsion system could be a solution, but it entails many design challenges. To solve these, a huge amount of well-prepared STEM (science, technology, engineering and mathematics) graduates will be required for years to come. The motivation behind the present work is to counteract the declining interest in STEM studies that has been detected in recent years [1]. Furthermore, STEM study graduates often lack well-developed soft and working skills, which are required to succeed in their subsequent careers. These challenges can be addressed by combining experiment-based learning for school students with a project-based learning approach for STEM students [2], [3], [4], [5].

This paper presents an approach, which enables university STEM students to develop and supervise experiments concerning scientifically relevant topics and conduct these with high school students. Thereby, the interest of high school students in STEM topics can be raised, while providing the STEM students with necessary working skills and expert knowledge. First of all, the motivation, the framework conditions, the procedure, potential benefits and a method for the evaluation of this approach are explained. Afterwards, initial experiments and the positive feedback from the STEM students are presented. Finally, a summary and an overview of potential future advancements of the approach are given. This very approach could contribute to an increased interest of high school students in STEM courses, while preparing STEM students for scientific careers and leadership roles.

II. Approach

A. Framework Conditions

1) Electrified Aircraft Propulsion

The political goals of limiting the effects of climate change from the Paris Agreement demand for a contribution of the aviation industry. Hence, the European Commission published the Flightpath 2050 to reduce CO_2 emissions of aircraft [6]. As a consequence, sustainable and regenerative energy sources, such as green hydrogen, are being investigated for utilisation in aviation. Thus, the aircraft propulsion system architecture needs to evolve. Hereby, numerous electrified propulsion system architectures have been identified for different passenger capacities and flight range requirements [7]. This electrification of the aircraft propulsion system can entail the introduction of various new components to the aircraft powertrain, e.g.

- types of hydrogen storage,
- generators, batteries and fuel cells
- high power electrical wiring,
- electrical power conversion,
- electric motors and gear boxes.

Furthermore, additional thermal management systems such as heat exchanger, cooling and heating systems will be required. The components of electrified powertrains can be integrated into the fuselage or a traditional nacelle, as shown in Fig. 1. Hereby, the fuselage-integrated concepts could improve the wing aerodynamics, while introducing challenges concerning heat transfer.

The topologies of electrified powertrains can be categorised in turbo-electric, all-electric and hybrid-electric architectures [8]. Turbo-electric architectures utilise generators, which are driven by respective gas turbines, to provide electrical energy to electric motors. All-electric architectures rely completely on galvanic cells, such as batteries and fuel cell systems (FCSs), for energy supply to the electrically driven propulsors. These architectures can be solely battery-based or fuel cell-based, where the FCS is supported by a battery, see Fig. 2. Such a fuel cell-based approach has been applied in the HY4, the first hydrogen fuel cell-powered four seater passenger aircraft [9]. Hybrid-electric architectures are a combination of the former topologies and include gas turbines as well as galvanic cells to provide energy to the propulsors. There, for example combinations of FCSs with the gas turbine compressor and turbine system as well as potential synergies are investigated.

While there are many concepts, electrified aircraft have not yet been introduced in commercial aviation, as they need to comply with the strict reliability, safety and weight requirements. Hereby, numerous challenges still have to be solved in terms of fail-safe operation, power density, thermal management and electromagnetic compatibility. This can be achieved by improving existing technologies, such as electrical motors and fuel cells, and adapting them for aviation as well as by designing innovative solution. These tasks will be a focal point of aviation research in the coming decades.

2) DLR_School_Labs

Currently, the German Aerospace Center (DLR) operates DLR_School_Labs at over a dozen different locations [10]. These are educational laboratories that offer pupils the opportunity to experience the world of research and technology. They can get to know the working methods and everyday working life of scientists, and also carry out experiments that correspond thematically with DLR research projects. Thereby, the research field can be aeronautics, space, energy and transport.

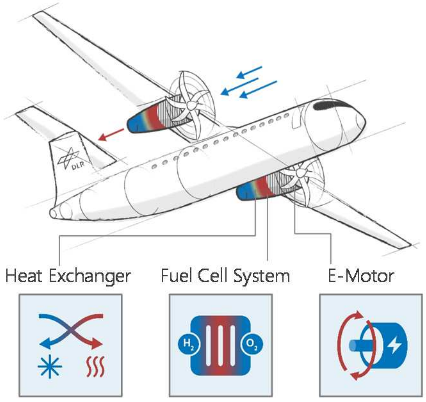

Fig. 1. Nacelle-integrated fuel cell-powered aircraft

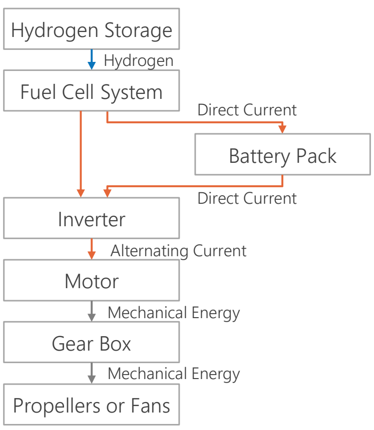

Fig. 2. Fuel cell-based aircraft propulsion system

DLR_School_Labs are primarily available to secondary school pupils, but also to elementary school classes. The experiments are individually tailored to the knowledge level of the school classes. Visits in the labs last one or more days and are free of charge. The school students are divided into small groups and guided by trained staff. Hereby, the staff supervises the experiments and can provide career guidance. The DLR is committed to awaken a fundamental enthusiasm for STEM in young pupils as well as to deepen their interest in upper grades and possibly motivate them to choose a corresponding study programme [10]. Furthermore, the aim is to convey the fascination of research. The laboratories contain state-of-the-art research facilities and high-tech equipment that schools do not usually have. By conducting experiments with reference to current research, the pupils gain knowledge and insights that go beyond the possibilities of school lessons. This way, teachers are provided with a varied addition to their lessons and the pupils can transfer the theoretical knowledge they have acquired at school in practice.

3) Institute of Electrified Aero Engines

In 2020 the DLR launched the Institute of Electrified Aero Engine in Cottbus to investigate electric propulsion options for sustainable aircraft. In this context, the establishment of the DLR_School_Lab Cottbus is being planned in cooperation with the Brandenburg University of Technology and the likewise newly founded DLR Institute of Low-Carbon Industrial Processes, compare Fig. 3. This laboratory shall be launched within the next years and it shall include experiments related electrified aircraft propulsion amongst others.

B. Experiment- and Project-based Learning Approach

The general goal of the present work is to introduce STEM students to the scientific work environment and to provide them with technical knowledge and improved working skills, while increasing the interest of high school students for STEM. This task is addressed through an approach, in which STEM students develop electrified propulsion experiments and supervise students in conducting them.

To carry out this approach, a researcher introduces three engineering students to topics concerning sustainable technologies for future electrified aviation and, moreover, to the scientific work environment of the DLR. Thereby, a project-based learning environment is created, in which STEM students prepare experiments on sustainable technologies over the period of six months.

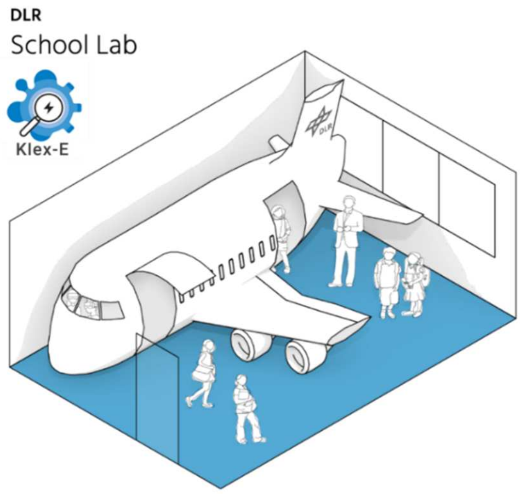

Fig. 3. Potential design of the electrified propulsion laboratory

These experiments are designed to demonstrate technologies, such as hydrogen fuel cells, power electronics and electric motors, and are eventually combined to electrified aircraft powertrain experiments. While designing the experiments, the STEM students are confronted with multidisciplinary challenges ranging from electrical and mechanical engineering to chemistry and industrial engineering. This way, they acquire new knowledge and consolidate existing expertise from their respective fields of study. Additionally, they develop valuable working skills, e.g. didactics, presentation skills and project management, while working independently and in a team. After preparing the experiments, the STEM students supervise high school students in conducting these experiments during project days. By this, they can consolidate and improve their technical knowledge and further improve their working skills, e.g. by guiding young people. This way, they are being prepared for scientific careers and leadership roles.

The high school students gain insight into the functionality and the challenges of sustainable technologies and electrified aviation. That knowledge growth is achieved by means of a deductive experiment-based learning approach [11]. This way, their interest in STEM topics can be raised or enhanced, so that the likelihood of them starting STEM studies can be substantially increased. Moreover, the high school students can become more familiar with university life and its differences to school routine through discussions with the supervising STEM students. Thereby, the participating schools get assistance in providing study and career guidance. The cooperating university could increase their number of enrolments. These new university students would also gain first insights in what to expect from university life and their course of study. This could have a positive impact on the dropout rate. Furthermore, the improved soft skills of the university graduates can contribute to a better reputation.

Additionally, the visibility of research institutions, such as the DLR, is increased. The experiments developed here are planned to be included in the DLR_School_Lab network [10]. Furthermore, the experiments can be used for internal training purposes or exhibited at public events to address the general society and politicians. Thereby, the social acceptance for innovative technologies, sustainable aviation and government-funded research can be improved.

C. Procedure

1) Acquisition of STEM Students

The design of electrified propulsion experiments is an ideal task for the familiarisation phase of student assistants in a research work environment. Hence, three STEM students have been newly hired as student assistants by the DLR Institute of Electrified Aero Engines to design the respective experiments under the supervision of a researcher. These university students had only little pre-existing knowledge of the field of electrified aviation. One of the students has undergone an apprenticeship as electronics technician and is studying electrical engineering. The other two students participated in a project-based approach [4], [5] during their schooldays, which lead to them studying industrial engineering. One of them also had some experience in supervising pupils.

2) Discovery Phase

During discovery or familiarisation phase the participating STEM students get to know each other as well as the researcher and the institute. This process is assisted by the weekly group meetings and the weekly individual meetings with the supervising researcher, which take place during all phases. Additionally, the university students are provided with basic knowledge concerning electrified aviation and theoretical soft skills, e.g. time management, information procurement, project management and didactics. Afterwards, ideas for potential experiments are gathered during several visits of school labs, literature research and brainstorming sessions. A suitable experiment should have relevance to electrified propulsion, be able to motivate the high school students and keep them sufficiently busy for the duration of their visit without overwhelming them. After one month, at the end of that phase, each student has a specific field of experiments and first conceptual ideas for said experiments, including necessary resources and a schedule.

3) Concept Phase

The concept phase has a duration of about two months and contains further literature research to acquire intensified in-depth knowledge concerning specific component technologies in electrified aviation. The conceptual ideas of experiments are further developed, the theoretical basics are documented and initial necessary equipment for mandatory experiments is ordered.

4) Detail Phase

During this phase of about two months, the first experiments are set up and extensively tested by the group to improve them. Orders are placed for better components of mandatory experiments and for optional experiments. Furthermore, a schedule, experiment instructions and presentations are prepared for visits in the planned lab.

5) Implementation Phase

In the final phase of about a month, backup plans in case of a schedule deviation are developed and evaluation forms for the high school students are prepared. Additionally, all planned experiments are set up and conducted for test purposes. First, this test phase is witnessed only by the group. Afterwards the experiments are conducted internally at the institute and then with high school students. After successful test operation, the experiments can be implemented in the DLR_School_Lab or shown at other public events.

D. Evaluation of the Approach

The feedback from the STEM students is obtained through individual conversations. The experience of the high school students will be collected with a questionnaire after participating in the laboratory to quantify their expectations, experience and general opinion, for instance concerning STEM careers, sustainable aviation and electrified propulsion, see Worlitz et al. [12].

III. Results

As the institute and the lab have just been commissioned, no high school student data could yet be generated with the lab in use. Hence, this section focuses on the current state of the experiments and the feedback from the STEM students.

A. Description of initial experiments

The experiments for electrified propulsion systems are divided into the groups electrochemical, power electronics and electromagnetic experiments. Each group contains multiple experiments of a similar field of study and is developed by a respective STEM student. Eventually, core experiments from all groups are combined to a downscaled electrified aircraft propulsion system.

The general didactic approach of each experiment group is quite similar. First, theoretical basic knowledge is taught. Hereby, a short presentation of at most five minutes is combined with interactive communication methods. Afterwards the theoretical knowledge of a specific experiment is explained. Then, the experimental setup and procedure are introduced. Subsequently, the experiment is conducted and evaluated. In case of a malfunction of an experiment, pre-recorded videos of the experiment are shown and questions are discussed. After all questions have been answered, the next experiment is explained and so on.

1) Electrochemical Experiments

The first group of experiments includes the generation of hydrogen (H_2) by electrolysis and the storage of hydrogen in metal hydrides as well as the generation of electrical energy with polymer electrolyte membrane (PEM) fuel cells (Fig. 4) and Daniell-cell accumulators (Fig. 5). Setting up the experiments and assembling the components, such as the fuel cell, is a crucial part in the lab, see Eichler et al. [11].

2) Power Electronical Experiments

The second experiment group contains experiments concerning semiconducting components, such as diodes and transistors. In a subsequent rectifier experiment the correct arrangement of the diodes must be determined experimentally to convert alternating current into direct current. In an inverter experiment switches must be operated correctly by hand to convert direct current into alternating current (Fig. 6).

3) Electromagnetic Experiments

The third group of experiments teaches the functionality of electric motors. It consists of experiments that explain the laws of electromagnetic induction, e.g. by proving induced current flows, magnetic fields and the Lorentz force. On that basis, a homopolar motor is built (Fig. 7) and different direct current electric motors are investigated experimentally.

4) Electrified Powertrain Experiments

In the final experiment of the planned school lab multiple metal hydride hydrogen storages, a 30 W PEM fuel cell stack, a 30 W direct current electric motor and a propeller are combined to form a low-scale electrified aircraft propulsion system, as is shown in Fig. 2.

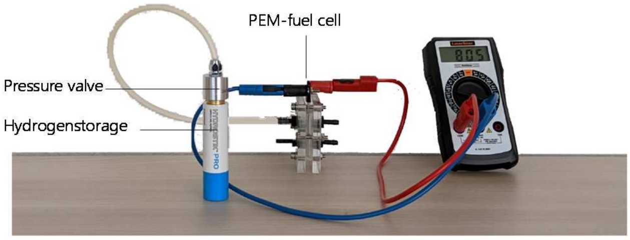

Fig. 4. Metal hydride hydrogen storage and PEM fuel cell experiment [11]

Fig. 5. Daniell-cell accumulator experiment [11]

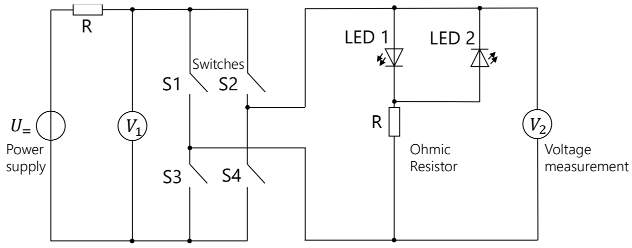

Fig. 6. Manual electric power inverter experiment

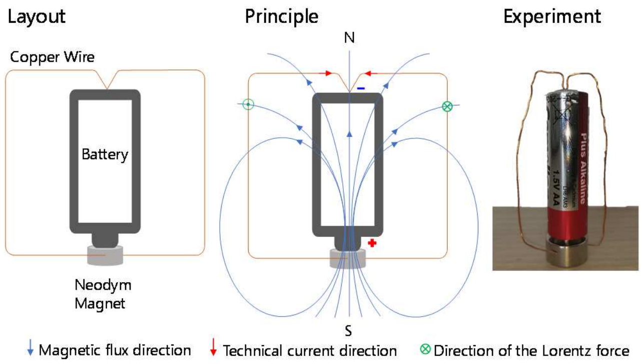

Fig. 7. Homopolar motor experiment

B. Feedback from the STEM Students

The first feedback from the STEM students is generally positive. They praise the extensive exchange, the huge growth in terms of technical and methodical knowledge, the opportunity to implement their own ideas and the initial exposure to work life. Their enthusiasm for aviation and a career in science has grown further, while their interest in teaching has decreased. However, final conclusions can only be drawn after the first sessions with high school students.

IV. Future Work and Conclusion

A combined approach of experiment-based and project-based learning has been presented. The approach enables STEM students to develop and supervise experiments concerning scientifically relevant topics and conduct these experiments with high school students. The motivation and potential benefits have been outlined. Initial experiments have been described and the positive feedback from the STEM students has been shown.

In the next step all planned experiments undergo a test phase. After successful test operation, the experiments can be utilised in the DLR_School_Lab or at other public events. Thereby, the interest of high school students in STEM topics can be raised, while providing the STEM students with necessary working skills and expert knowledge. This will be evaluated via student questionnaires before and after participation in the lab. Furthermore, the STEM students can further develop their working skills and prepare themselves for their future careers. The long-term effects of this approach on the enrolment of students, their dropout rates and the improvement of the students' soft skills have to be monitored.

In conclusion, this very approach could contribute to an improved social acceptance for innovative sustainable technologies in aviation and an increased interest of high school students in STEM courses, while also preparing STEM students for scientific careers and leadership roles through improved working skills.

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