Extending STEM Education to Engineering Programs at the Undergraduate College Level

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Abstract—Science, technology, engineering, and mathematics (STEM) education is gaining wide attention. STEM education assimilates rigorous disciplines and requires diverse skills. Effort to promote and integrate STEM education in schools has been significant during the recent years. This paper investigates promoting students interest in STEM beyond the K-12 levels outside the US. The investigation targets the American University of Kuwait, where the educational community in general, and the students in particular, are faced with different challenges. Comprehensive proposals are suggested to extend STEM education to be part of the Engineering programs at the undergraduate level, with focus on Electrical, Computer, and Systems Engineering. Remedies for overcoming the weak background in mathematics and sciences, for many students, are explored. In addition, parallel laboratory-based educational components are applied, for selected courses, to enhance the technological aspects via providing deep hands-on experience and exposure to real-life scenarios. Incorporating STEM education in courses/labs, academic activities, extracurricular activities, capstone design projects, internships, and satisfying accreditation requirements are addressed. A thorough discussion is presented to include analysis of best practices, evaluations, examples, and case studies from the local and regional institutions.

Keywords—STEM education, Engineering education, ABET Accreditation, IEEE Student Branch, and Multidisciplinary research

1 Introduction

Students learn best when encouraged to construct and apply the knowledge they acquire through direct interaction with the world around them [1]. This can be achieved by adopting a project-based learning approach that integrates STEM education within the curriculum and allows students to deal with real-world scenarios, interact with each other, and develop feasible solutions [2]. For such reasons, STEM education was announced in the US on January 31, 2006 as an American competitiveness initiative. Consequently, it received significant increases in federal funding for advanced research and development programs, especially for advanced research in the physical sciences. It also increased the number of US higher education graduates within STEM disciplines. Some modern schools are currently dedicating some of their programs to STEM education [3]. Ever since, the concept of STEM education spread all over the world and many schools and universities are currently applying it in the Middle East and North Africa (MENA) and the Gulf Cooperation Council (GCC) countries.

Failure to acquire the basic knowledge from both math and sciences during the K-12 period greatly affects the progress of students during their college studies. Major problems were reported in the US regarding graduates from high school neither being prepared for adopting a new career, nor joining a college program [4]. A similar situation is happening in Kuwait, where many college students don't possess the required skills for the 21st century. The required cognitive, communication, and social skills need to be carefully developed over time so that students can cope with the more advanced and challenging situations that they must face during their undergraduate studies. There is always a debate whether science courses alone can prepare students to engage in life-long learning. This is because sciences curricula focus on facts and problems that have a well-known unique and clear answer, which is not necessarily true, in real life. Many science problems can be ill-defined or can have a variety of solutions, where only a few of them are feasible. In addition, many real-world problems have requirement conflicts that need to be resolved or solutions that need to be optimized [1, 3].

Math, on the other hand, is considered a tough discipline by many students. Due to the rapid advancement in digital computing and information technology, students rely on computer-aided tools to do the work for them. Although this serves the purpose of calculations, most of the time, more and more students lack the deep understanding of the basic concepts. Consequently, this leads to difficulties in understanding advanced topics that require difficult analytical skills, in contrast to the relatively easier numerical skills. Programs like MATLAB will surly extend the power of computing for many students; however, excessive usage of such automated tools kills the need for deeper understanding of many mathematical and scientific subjects [5]. These identified challenges call for a strong need to learn by doing, by design, and by applying the knowledge and skills, acquired through the educational program, while interacting with the surrounding environment and meeting realistic constraints.

Many research institutes are now outreaching for colleges and universities, at the undergraduate level, to establish STEM centers. These centers aim to involve faculty members and students in the process of integrating STEM education in developing curricula and other academic activities that include both teaching and conducting research. The Department of Defense in the US is currently offering internships for high-school and college students and gives them the opportunity to use their laboratories and facilities to engage in solving real-world problems and gain the required experience to become leaders and scientists [6]. In Kuwait, a similar approach is adopted, at the Kuwait Foundation for the Advancement of Sciences (KFAS). KFAS launched the Science and Math Education Program that integrates all the aspects of the education process into three main taxonomies, the messenger (educator), the message (teaching/research materials), and the recipient (students) [8]. This program aims at building teachers' capacity, enriching Arabic educational content, and establishing programs to mentor sciences and Math students. KFAS also supports using interactive teaching materials, forums, physics and Math Olympiad to promote STEM education. Other similar projects were initiated by other foundations such as Kuwait Institute for Scientific Research (KISR) that organizes annual project-based Summer camps for students from high-school and both governmental and private universities; in addition to the Ministry of Education and the Ministry of Social Affairs. These local activities are quite similar to many US project-based integrated STEM programs that adopt five stages: reflection, research, discovery, application, and communication [1-6].

The rest of this paper is organized as follows. Section 2 formulates the problem at hand and explains the need to promote a STEM-based approach for the Engineering programs at the undergraduate college level. In addition, strengths and challenges of the suggested proposals are highlighted. Section 3 presents the three STEM-based proposals. Section 4 presents a thorough discussion that includes analysis of best practices and evaluations. Finally, Section 5 concludes the paper and sets pointers to future works.

2 Problem Formulation

Students are usually faced by many barriers during their high school and college life. Student barriers may be psychological, technological, and pedagogical. This can greatly affect their readiness to achieve the required goals from their programs of study and, later, to excel in their careers [7]. With focus on engineering programs, students are required to start their first year in the college, while having the required breadth and depth in Math and sciences, especially physics and chemistry. Many universities dictate a foundation program, if students fail to achieve a prescribed level during the admission process. The biggest challenge in this case, is how to build on a previous STEM education program, whether being successful or not.

Many engineering colleges in the MENA and the GCC regions adopt the American model for their engineering programs with focus on Liberal Art aspects, as required by ABET accreditation. The American University of Kuwait (AUK) is a private Liberal Arts institution that offers engineering programs. According to ABET, the biggest engineering accreditation agency in the world, the term engineering is defined as: "Engineering is the profession in which a knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind" [9]. Thus, solid background in both Math and sciences are strongly required. To supplement any shortcomings in the STEM education during the high-school level, the curriculum, activities, supporting personnel, and the environment, including the facilities, of the engineering program should address the following issues, as related to students:

- Motivate students to complete project-based assessment components via offering them a variety of options and alternative designs.
- Help students to fully-understand the problem at hand and its practical real-world nature that might be different from the too perfect facts from science.

- Allow students to work in groups, with minimum coaching from the faculty members, and to depend on simulated models, before actual implementation of their designs.
- Ask students to perform SWOT analysis for their team and their final product and to launch surveys to solicit feedback from experts in the same field.
- Inform students about the rubric used to evaluate their performance and use a consistent evaluation method to allow fair grading.
- Encourage students through allowing second chances and explaining the correlation between their work and the learning outcomes of their program.
- Reward students via allowing and promoting showcases, galleries, conferences, or any other means, where they can exhibit their work.

Many challenges exist when trying to achieve the above noted aims. The challenges exist at many levels; students, faculty members, and the administration of the institution. These challenges can be highlighted in the following points:

- Tailoring the curricula of courses/labs to account for project-based assessment components and to devise a robust assessment scheme for them.
- Asking faculty members to provide extra help, outside the regular class time and office hours to closely monitor the performance and the progress of the students.
- Deciding on the deliverables of the project and how to provide evidence for the individual effort of each team member.
- Facing the reluctance of some students and some faculty members to learn new stuff and devote extra time for a nontraditional learning process.
- Allocating enough funds to support various activities to purchase, assemble, and build the necessary prototypes for the projects.
- Allowing for extra open-lab hours, free tutorials, and peer review, which is very time consuming and may require additional budget.
- Convincing students to participate in competitions and conferences to present their work, which might conflict with the schedules for their courses/labs and/or exams.

These challenges need to be carefully analyzed and feasible solutions must be proposed, especially for institutions that are mainly a teaching institution and limited incentives are available for conducting research and/or projects.

3 STEM-Based Undergraduate Proposals

By default, most engineering programs are, some way or another, STEM-based, since they depend heavily on Math and natural sciences. ABET accreditation requires a certain number of credit hours for Math and sciences to fit the required programs criteria, e.g. Electrical Engineering (EE) is required to reflect statistical analysis, while Computer Engineering (CE) should reflect the existence of Discrete Math. The design of the program structure must be carefully done to include all the necessary prerequisites for courses and labs.

3.1 Case study I

A major course in Electrical Circuits is usually required for many engineering programs such as EE, CE, and Systems Engineering (SE). Figure (1) shows part of the program structure highlighting this course at the AUK, with its prerequisites and concurrent courses/labs. Clearly, the arrangement shown in the Figure adopts a STEM-based approach, where there are a group of Math courses, science courses, and a technology-based lab, in conjunction with this course. Arrows with a single head stand for prerequisites, while arrows with double heads stand for concurrent. It should be emphasized that, without loss of generality, only the Electrical Circuits (ELEG 220) course was exemplified in Figure (1); however, a generic structure for a STEM-based Engineering course would be identical, except for the details of the contents.

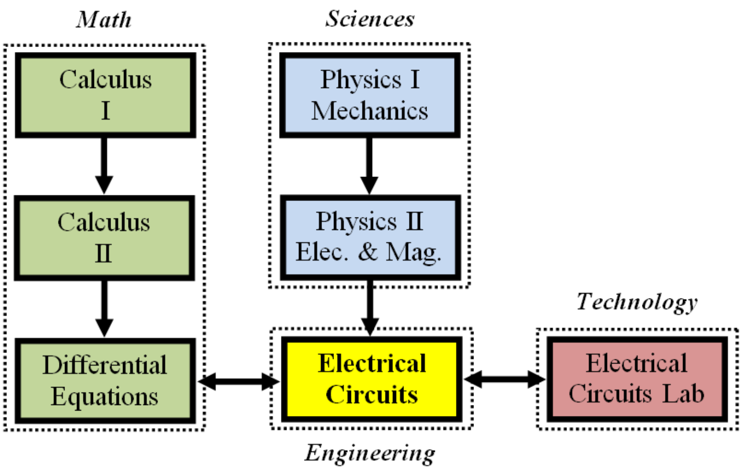

Fig. 1. Layout of a STEM-based structure for a sample course

Evidently, this course builds on the Math and sciences knowledge, previously gained in Calculus I and II, and Physics I and II. In addition, it has a concurrent laboratory component that uses practical experiments to promote the learning of the theoretical concepts.

Table 1. Math-related CLOs and their ABET SOs mapping

(1)	Apply algebraic techniques to solve simultaneous equations
(2)	Solve linear differential equations
(3)	Use complex numbers

(a)	An ability to apply knowledge of mathematics, science, and engineering
(e)	An ability to identify, formulate, and solve engineering problems

Table (1) shows the explicit Math-related course learning outcomes (CLOs) and their mapping to ABET student outcomes (SOs). The first CLO is related to applying different theories and techniques to analyze and design linear resistive circuits, where students must usually solve many equations related to finding the two most important variables, voltage and current. The second CLO is related to analyzing and designing circuits that contain energy storage components, such as inductors and capacitors, while the third CLO is necessary, when dealing with ac-based circuits.

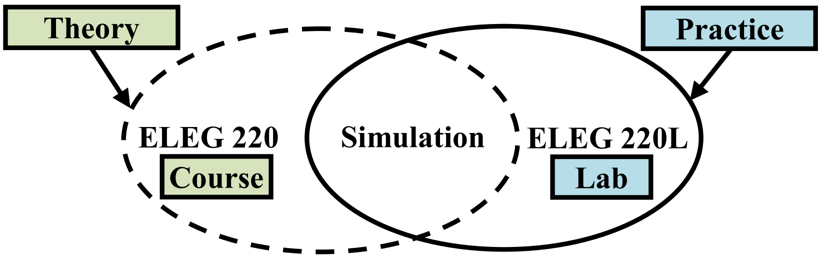

Fig. 2. Layout of the course ELEG 220, and its concurrent lab, ELEG 220L

Figure (2) further illustrates the layout of the ELEG 220 course and the overlap with its lab component, ELEG 220L. Effectively using a simulator is a mutual CLO between the course and the lab to implement the STEM-based structure. Simulators act as virtual labs and promote the understanding of the students, via running demonstrations, using many built-in libraries that mimic the exact behavior of the practical components. Simulators allow integrating theory with practice and accelerate creating prototypes for the required designs. Certainly, this promotes the STEM-based nature of the course/lab. Based on the reported results, the success rate for running simulations and building the designed circuits were 92% and 83%, respectively.

Students are given a project to design a controlled current source. They were divided into small groups of three-four students so that they can practice team work and time management skills. The topic was challenging, as this is the first technical course in their program and they only had access to constant voltage sources in the lab. The project motivated them to gain more knowledge about what the theoretical problems in the course that deal with current sources represent in practice. Moreover, many students expressed their satisfaction about this selected topic and were very keen to finish their project and present the final product in a working order and to prove its accuracy via comparing practical measurements with simulation results. Having a clear description for the required tasks helped removing any ambiguity about the deliverables and the assessment scheme of this project-based learning process. Based on the feedback from the students, most of them were stimulated to engage in an activity that included calculations, simulations, design, implementation, and verification of a multidisciplinary topic. In general, their average scores for this project were around 85%, compared to the theoretical exams and the overall score for the course that were 65% and 75%, respectively. This was an indication that learning through a project is more beneficial. Figure (3) depicts a comparison between the average percentage scores for the project-based assessment components versus the overall percentage scores for the ELEG 220, for seven consequent semesters, starting from Fall 2014 (FA14) to Fall 2017 (FA17), including three spring semesters (SP15-17). The results show that students were always performing better in projects, compared to theoretical exams. The consistency of these reported results strengthens the fact that STEM-based learning components enhance the attainment of CLOs and promote the understanding of the course material.

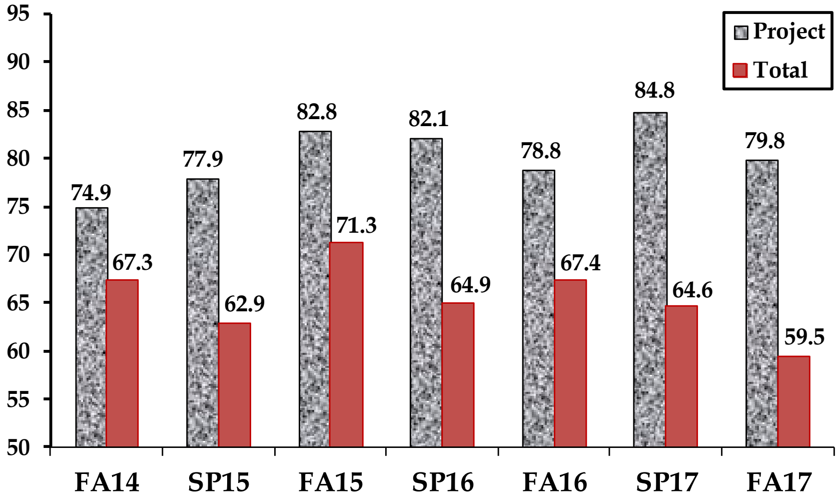

Fig. 3. Average performance of the students in projects vs. the total scores in ELEG 220

As for the challenges faced in this STEM-based project, the following were the most important ones:

- Mapping the objectives of this project to fit both the learning outcomes for the course and its concurrent lab component.
- Devoting extra open-lab hours to allow students to gain access to the lab facilities. This needed an extra budget for the lab technician, which required a strong justification to represent to the higher administration of the institution.
- Assessment and evaluation of this project proved to be time consuming, as it required validation of the functionality of the practical components, in addition to, matching many results with their simulated equivalents, and finally reading many lengthy reports.

Despite all challenges, it was decided to maintain this good practice and to encourage students to enlarge their projects and to present them in future exhibitions and undergraduate research conferences.

3.2 Case study II

All students in engineering programs are required to have a capstone design project (CDP) in their final year. CDPs can be one-year long and are the most important learning experience that reflects the knowledge and experience that is gained throughout the whole years of the program. At the AUK, the CDP extends for two semesters and its prerequisites are very carefully designed. Figure (2) shows the requirements for students to start their CDPs and join a technical team [10, 11].

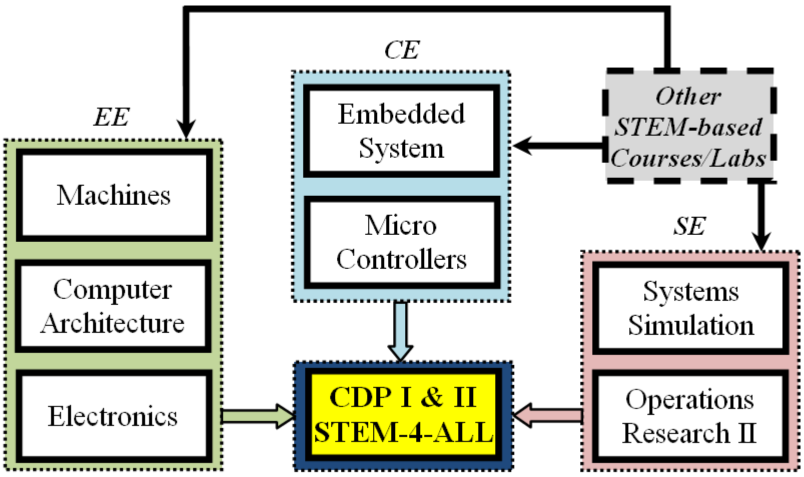

Fig. 4. CDPs and their pre/co-requisites

When students prepare their proposals for the CDP, they should also join a technical team to perform extra academic activities that are related to their CDP topics; e.g. joining automation, multimedia processing, or robotics teams [12-15]. Technical teams include students from different CDPs that have a common interest. One of these technical teams is STEM-4-ALL, where students participate in competitions that rely on applying knowledge from STEM-related subjects. Technical teams combine students from different CDPs, which is an excellent opportunity to interchange ideas and acquire team-work skills. Students are required to organize an exhibition/seminar to demonstrate their work. In many occasions, students communicate with funding agencies that help them, both financially and practically.

STEM-4-ALL was developed within the IEEE Student Branch at AUK to cover aspects, such as, hardware and software design, industrial training, "Engineering" afterschool, school projects, engineering video games and toys, engineering education, engineering design, engineering physics, systems engineering, computational chemistry and biology, etc. [14]. Encouraging students to join the STEM-4-ALL technical team and inspiring them with ideas is very helpful, as students manage to come up with out-of-the-box solutions to many real-world problems and they can also succeed in working under pressure, with realistic constraints, and deal with people of different age groups.

3.3 Case study III

Faculty members should also engage in STEM-based activities, as a continuation for the role of teachers at the high-school level. The following motivated the inclusion of STEM-based research centers that bring together faculty and students:

- Bringing together many researchers at the academic institution, who are working in isolated islands, without knowing that there exist many mutual interests between them.
- Trying to better serve the community via establishing a link between the academic institution and many agencies in education and industry.
- Allowing for small grants to involve undergraduate students in performing research, as this will prepare them for their higher studies and establishing their careers.

In the region, there are currently an existing group in Zewail city in Egypt with similar centers in KAUST in KSA, and Khalifa City in UAE. In addition, Kuwait University is planning to have a STEM center in its newly proposed research park. A similar center is now being proposed at the AUK, with the following objectives:

- Crossing the gap between theory and practice, which is a major concern when establishing new research fields.
- Connecting theoreticians to experimentalists to accelerate and robustify research and engaging many faculty members from different backgrounds, especially from service departments such as math and natural sciences
- Providing means of research coordination and orienting it toward research priorities in the region.
- Proposing innovated fields of study that can attract students with outstanding performance from all over the MENA and the GCC region and promote the quality of undergraduate capstone projects.
- Constructing a consultation and training center in liaison with the industry, which brings more internship opportunities to the students in the STEM fields.

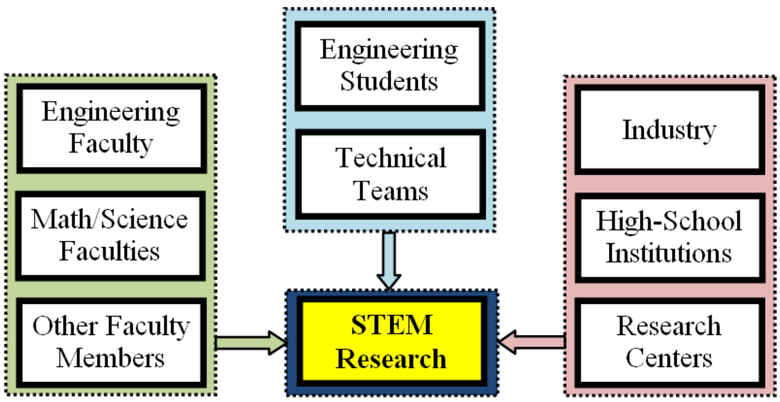

Fig. 5. Proposed structure for STEM-based research center

Figure (5) shows the proposal for the STEM-based research center and its suggested involved parties. Coordination between the Ministry of Education, Ministry of Social Affairs, and the Private Universities Council is required to establish such center in the AUK.

4 Discussion

In this section, we provide a general evaluation of the suggested STEM-based proposals, highlight their relationship to ABET Accreditation Criteria [16], and discuss similar investigations [17-20]. The paper presents three proposals for extending STEM education to engineering programs at the undergraduate college level. The proposals include curricular, extracurricular, pedagogical, and support-facilities aspects. The three proposals can serve as patterns of development and can lead to promising practices. The results from applying the first and second proposals at the AUK reflect their effectiveness in application. The programs adopting the proposed STEM-based pattern are recently accredited by ABET [11]. The AUK IEEE Student Branch and the technical teams have made several significant contributions and received awards within the GCC region [12]. Although the third proposal is still work in progress, significant preparatory implementation steps are completed including, the development of student teams structure and a research committee that is charged to lead the initiative.

The suggested STEM-based proposals can effectively contribute to the requirements of program accreditations, such as ABET Criteria. The three proposals can play a vital role in preparing students to attain the program educational objectives (ABET Criterion 2). In addition, the proposals can contribute to the attainment of all Student Outcomes (a) through (k). With no doubt, the proposals contribute to students' ability to apply knowledge of mathematics, science, and engineering, conduct experiments, analyze and interpret data, design within realistic constraints, function on teams, understand professional and ethical responsibility, communicate effectively, possess the knowledge of contemporary issues, engage in lifelong learning, and modern engineering tools necessary practice (ABET Criterion 3). Moreover, the suggested STEM-based proposals provide unique opportunities of improvement that can enable effective closing of the assessment loop (ABET Criterion 4). The contribution to the curriculum is evident through the effective application of the identified STEM-based pattern of courses (ABET Criterion 5). Furthermore, the proposals can improve the adequacy of student-faculty interaction, activities, and interaction with practitioners and employers (ABET Criterion 6). The third Proposal can contribute to the creation of an atmosphere that is conducive to learning and enables the availability of modern tools and equipment (ABET Criterion 7). Indeed, the implementation of the suggested proposals is an important evidence of institutional support (ABET Criterion 8).

The importance of STEM education is currently well-known world-wide. In [17-19], the authors highlight the need for STEM-based skills, activities, etc., in the MENA and GCC region. In [17], the authors reflect on their best practices, within the college of engineering. The reflection includes stressing the need to address the lack of student motivation, commitment, and self-agency. In addition, the reflection discusses the positive effect of activities on the identified challenges. Abu Almaati et al., in [18], present several STEM-based initiatives that promote the sustainability of education at the AUK. The presented initiatives include contextualizing the CE program within the context of Liberal Arts, student activities, and global collaborations. Wiseman et al., in [19], present results from the 2011 Trends in International Mathematics and Science Study. The results provide labor market expectations and data related to STEM education from all participating GCC countries. The paper present significant conclusions as related to STEM education and confirms its importance in addressing challenges, such as, human capital involvement, employment, and contribution to private sector. In [20], the author suggests metrics for efficacy in robotics programs. The main purpose of the investigation is to align ABET engineering student outcomes with K-12 STEM educational practices.

5 Conclusion

STEM education is witnessing great interest all over the world. This paper illustrated the ongoing activities at the AUK to establish a STEM-based educational and research system. The current project to extend STEM education, from high-schools, to undergraduate engineering programs is based on three main streams, tailoring the curriculum to foster STEM objectives, while satisfying accreditation requirements, enriching the CDPs via requiring STEM-related technical activities, and finally augmenting STEM-based research to connect faculty members with students, industry, and research centers. Future work includes mining through additional courses for STEM-based patterns. In addition, future work can include verifying the effectiveness of the STEM-4-ALL team through activities. Indeed, future work includes exploring methods and activities to support the structure for STEM research center.

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