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On the Bachelor Program in Engineering Physics for Underdeveloped and Developing Countries: Vision for Global Competitiveness

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ABSTRACT

The importance of a Bachelor Program in Engineering Physics for underdeveloped and developing countries is discussed in this paper. Worldwide rapid developments need reliable engineering graduates with strong inter- and multidisciplinary academic qualifications. Anticipating this requirement, Bachelor degree program in engineering physics is regarded as the most suitable for preparing graduates in underdeveloped and developing countries with such qualification profile. Several studies showed that the need for such educational program is quite promising. The motivation to strive for higher qualifications is strong, and it is motivated by individual as well as the institutional consciousness, as also triggered by labor market requirements and government's incentives. It is not surprising that the similar qualification profiles are already well designed in many industrial countries for Master up to PhD levels. Since the program requires a cross-discipline study among many fields, this paper also discusses the synergistic clustering strategy for facilitating the learning, research, and developmental activities. In this paper, seven clusters are proposed, namely generic knowledge, basic knowledge, instrumentation and control, energy and environmental engineering, materials, acoustics and vibration, and photonics. The cluster courses can be distributed in each semester depends on the department strategy of achieving the learning outcomes. Mandatory courses for such program are also being addressed as well.

Keywords: Engineering Physics; Bachelor Program; Inter- and Multidisciplinary Academic Qualifications

ABSTRAK

Pentingnya Program Sarjana Teknik Fisika untuk negara-negara berkembang dibahas dalam makalah ini. Perkembangan pesat di seluruh dunia membutuhkan lulusan teknik yang handal dengan kualifikasi akademis antar dan multidisiplin yang kuat. Mengantisipasi persyaratan ini, program sarjana teknik fisika dianggap paling sesuai untuk mempersiapkan lulusan di negara-negara terbelakang dan berkembang dengan profil kualifikasi tersebut. Beberapa hasil penelitian menunjukkan bahwa keperluan untuk dibukanya program ini cukup menjanjikan. Motivasi untuk mencapai kualifikasi yang lebih tinggi cukup kuat dan termotivasi oleh pribadi, keperluan institusi juga oleh pasar tenga kerja dan insentip pemerintah. Tidak mengherankan jika profil kualifikasi serupa sudah dirancang dengan baik di banyak negara industri untuk meraih gelar Master sampai ke tingkat PhD. Karena program ini memerlukan studi lintas disiplin di antara banyak bidang, makalah ini juga membahas strategi clustering sinergis untuk memfasilitasi pembelajaran, penelitian, dan kegiatan pengembangan. Dalam makalah ini, diusulkan tujuh kelompok bidang keahlian, yaitu instrumentasi dan kontrol, teknologi energi dn pengkondisian lingkungan, ilmu bahan, akustik dan getaran, dan fotonika. Subjek dari masing-masing kluster dapat disebarkan dalam tiap semester bergantung pada strategi department dalam mencapai tujuan pembelajaran. Kuliah wajib untuk program semacam itu juga didiskusikan di dalam makalah.

Kata kunci: Teknik Fisika; Program Sarjana; Kualifikasi Akademis Antar dan Multi Disiplin

INTRODUCTION

In the last decade, progress of science and technology experienced rapid acceleration that has never been predicted before. This rapid development needs the presence of experts, who are not only highly motivated but also reliable and have strong academic and technical qualifications (Sharma et al. 2017). On a higher level, these qualifications are not only limited to scientists and engineers, but also to bureaucrats, industrialists, and decision makers. As the nation's development and industrial progress becomes increasingly more complex, it requires the presence of intelligent and well educated graduates with solid academic background.

Rapid development of science and technology has changed the paradigm of study and its implementations, which is transformed into an inter-integrated and multidisciplinary pattern. Such a trend is inevitable due to human curiosity on various phenomena, increasing complexity of human daily life problems and for the sake of advanced techniques to solve such complex problems (Seay 2015). The ability to synthesize inter-disciplinary scientific fields and ability to quickly integrate them, adaptability to latest developments in science and technology issues will increase the person's adaptability and flexibility. This kind of person is then capable to cooperate and organize different scientific fields in achieving bigger and comprehensive goals, especially in dealing with challenging tasks in developing newly advanced technologies (Baetu 2017).

Thus the need of preparing human resources with such broad academic competences, as well as practical abilities in various fields, is an academic challenge. Human resources with this wide capacity must be carefully prepared, requiring the availability of a more advanced and integrated program (Zhang 2009). The educational program in engineering physics is aimed to cope with these challenges, i.e. expected to prepare engineering graduates who are qualified to contribute in developing and managing integrated science and technology (Physics Department Stanford University).

A preliminary study had been conducted and showed that the need for such educational program is quite promising. People's motivation to strive for a higher qualification is strong, and it is motivated by individual as well as the institutional consciousness, as also triggered by government's incentives. In most of the developed and industrialized countries, the Engineering Physics as a study program is offered ranging from Bachelor to a PhD levels. Most of the offered programs are concentrated in the US, as not surprisingly due to availability of adequate well-equipped research infrastructures (Lekso 2015). In this country, a PhD level is considered as an ultra-specialization for many academic interests, even some uncommon specific research topics can be successfully and smoothly implemented without any significant opposition from public, and this country is regarded as an ideal home for inter- and multidisciplinary research initiatives (Benn et al. 2016).

It is known that many researches in PhD levels produce new developments which are then realized as new industrial products. Educational programs at PhD level that offer a world-class Engineering Physics studies are of special interest, each with their own specialization, scope, and emphasis on specific developmental fields, as can be listed in the following examples:

1. PhD in Engineering Physics, Michigan Technological University (MTU): This program emphasizes new discoveries to resolve current and future technical problems in a multi-disciplinary way, regardless limits from both of classical physics and engineering concepts. The research development areas are: quantum modeling of nanoscale materials for electronics, Computational solid-state theory and materials science, cloud physics, chemical and biological sensors, near-band-edge and near-resonance phenomena of magneto-photonic crystals (Department of Physics, Michigan Technological University, 2019).
2. PhD in Applied and Engineering Physics, Cornell University: offers a research-based doctoral program, which combines the core curriculum of physics with studies and research that bridges the physical sciences with technical applications, as well as their interactions with other fields of science. The research development area is stressed in a combination between fields of nanoscience, photonics, biophysics, new materials and advanced instrumentation (Cornell Engineering 2019).
3. PhD program in Engineering Physics, University of Virginia: This program provides a strong mastery base and integrated field of physics, engineering and mathematics to its students. It is expected that the graduates have solid mastery of fundamental science and are able to apply their knowledge to various engineering problems. The program develops computational materials modeling, intelligent processing of materials, energetic particle interactions (ions, electrons and photons) with surface, nano-electronics, biology and medicine, energy and environment, and spintronics (The University of Virginia 2019).
4. PhD program in Engineering Physics, MIT: The program gives students a strong understanding of the various fields of multi-disciplinary science between basic science (including chemistry, materials science, mathematics, physics, biology) and engineering. It designs the graduates in performing developments of complex integrated systems: e.g. optoelectronics, photonics, plasma fusion, communication and quantum computing, MEMS systems and microfluidic structure (Massachusetts Institute of Technology 2019).
5. PhD program in Engineering Physics, Queen's University CA: The study offers a cross-cutting doctoral program of science, physics and engineering to improve the quality of life and solve future humanitarian problems in Canada and other parts of the world. The research area including nano-photonics, light-matter interactions, nano-devices, semiconductor optoelectronics, computational electrodynamics, quantum information technologies, glancing angle deposition, optics of anisotropic thin films and materials, nanoscale electronics and mechanics, organic and polymer light-emitting devices, small-angle x-ray scattering, ultrasonic imaging, clinical cancer care, radiation physics, non-destructive stress evaluation (Queen's University 2019).
6. PhD program in the Department of Physics and Engineering Physics, Tulane University: The program stressed on the physics of fundamental structures, properties, and processing of materials by working with other disciplines (Physics And Engineering Physics, Tulane University 2019).

Therefore, there are no specific phrases to formulate the nature of engineering physics in a short sentence. This program is designed to cope with frontier technology for the next decades. It is also important to call for the industrial involvement to influence the direction of university research activities. The current tendency shows that multinational companies are managed to relocate their manufacturing facilities into third world countries, which offer more competitive labor wage (Xu & Ouyang 2017). It is considered to be more efficient, and their headquarter offices will dealing only with research and developmental effort, establishing standard operating procedures and policies to protect their intellectual properties (Grieben & Sener 2017).

Thus it is not perceivable for the underdeveloped and developing countries to miss such a good opportunity. A similar program but devoted and designed for undergraduate level can be created, which is more than just "to fill the gap" but more importantly due to the needs for higher level are still not indispensible. This bachelor program is regarded as beneficial for providing the students with inter- and multidisciplinary competencies such as engineering analysis and skills, which are more required to solve engineering problems in their communities. Such competencies are more suitable to backup the country-based manufacturing, as more suitable implemented in underdeveloped and developing countries, where the numbers of capital, technological, as well as trained human resources to pursue industrial developments are limited.

In the past, where country-owned infrastructures for information system were not well developed, the above mentioned educational role model was not clearly understandable by the concerned government officials, as it leads to policies that were haphazardly regulated [16]. But recently with the advancements of information technology (IT) where all information can be easily accessed, the underdeveloped and developing countries have more opportunity to anticipate the world's trends, including the current trends in the education with multidisciplinary aspects, like the engineering physics. In this case, the bachelor program is a reasonable option for underdeveloped and developing countries since the required educational facilities and infrastructures are within the reach of available resources. The bachelor program is designed to give students to strengthening themselves to wider areas of engineering expertise, based on the future and latest technological developments, as will be discussed in the next two sections. Thus a bachelor study program in engineering physics is essentially *a melting-pot* of basic sciences, such as physics, mathematics, chemistry, and biology, with the fundamental concepts of engineering. Nowadays a multi- and interdisciplinary scientific approach is more thoroughly addressed for solving various complex engineering problems.

VISIONS TO FACE CLOBAL COMPETITIVENESS CHALLENGES

Frontier science and technological advances require the availability of broad competencies for guiding theoretical developments in science and innovatively engineering their implementations. The survey of trend in research and developments in advanced technologies in the 21st century had been done and will be summarized below. And focused areas of developmental technologies are photonics, green energy, biomedical and genetic engineering, intelligent control, advanced materials, as well as computer processing, modeling and computing. It is also important to note that the National Academy of Engineering during the Chicago Summit in April 2010 had released 14 challenges in Engineering for the 21st century, i.e.

> "make solar energy economical, provide energy from fusion, develop carbon sequestration methods, manage the nitrogen cycle, provide access to clean water, restore and improve urban infrastructure, advance health informatics, provide better medicines, reverse-engineering the brain, prevent nuclear terror, secure cyberspace, enhance virtual reality, advance personalized learning, providing the tools of scientific discovery (National Academy of Engineering 2019)."

The US government has also embarked on a cross-disciplinary courses and trainings in the national educational process to produce prospective scientists and engineers and the new generation of skilful labors (The White House, 2019). Meanwhile the EU Commission also decided to adopt a multidisciplinary and cross-cutting approach to the development, convergence and integration of their key enabling technologies areas, i.e. covering multi- and interdisciplinary areas like nano-technology, micro- and nano-electronics, photonics, advanced materials and biotechnology (European Commission, Research, Technology and Innovation 2019).

Moreover, various funding initiatives on a national scale as well as in the form of international consortiums have been devoted enormously, with a goal of creating superior new technologies for human life, i.e. in the context of excellence in performance, environmentally safe, low energy consumption, and sustainable. Some examples of these initiatives are described as follows:

1. *Materials Genome Initiative*: to enable multidisciplinary and interdisciplinary collaboration to gain new innovations in the research of material science, shortened time for the development of new types of materials is highly needed by public health services, green energy, computer processor technology as well as national security programs. The program is funded by the National Science Foundation (NSF) and the US Department of Energy (DOE) (US Office of Science and Technology Policy 2011).
2. *Human Genome Project*: a collaborative international research project led by The U.S. Department of Energy (DOE) and the National Institutes of Health (NIH) to identify and map about 20,000 – 25,000 genes contained in human DNA. This inter- and multi-disciplinary research, which began in 1990 and completed in 2003, also aimed to identify the millions of combinations of chemical bonds that make up human DNA. The continuing applications of this research is very vast, covering development of new technologies in the areas of food security, medicine and healthcares, clean energy

and environmental stewardship, and law-enforcement-related technologies (U.S. Department of Energy Office of Science, 2019).

3. *Energy Innovation Hubs*: the collaboration of several research centers to apply an integrated approach between basic sciences, applied science and engineering skills to accelerate the discovery of new technologies related to critical issues in the field of energy security. Divided into clusters such as nuclear energy, solar energy, energy efficiency in buildings, critical materials, cluster for wind turbine applications, electric vehicles, solar cell panels, and for energy-efficient lighting (U.S. Department of Energy 2019).
4. *Brain initiatives*: the initiative to build research collaborations that has just been launched by the US government with a funding of USD 300 million per year and will last up to 10 years. The purpose of this inter- and multidisciplinary research collaborative project is to understand how the brain functions in thinking, learning and remembering, and mapping out the activity of every cell (neuron) in human brain. The long-term outcomes of this study is extensive, i.e. a) Better understanding of the mechanisms of Parkinson's disease, to improve treatment, prevention and cure schemes. b) Addressing the problem of language barriers through advances in human-machine interface technology, which is the interface between computer systems and detectors (The White House 2019).
5. *European Commission's Future and Emerging Technologies (FET)*: a cross-scientific progress initiated by the EU commission to facilitate a long-term innovative research related to the development of information and communication technology (ICT). The mission is to conduct high-risk research efforts – potentially providing breakthroughs or impacts for the wider community that is exploring new radical ideas and future research and innovation trends. The topics are non-conventional computing, reducing energy consumption from computer processing systems to their minimum limits, complex multi-level system dynamics, quantum ICT, neuro-bio-inspired systems and so on. The expectation of this initiative is to perform new findings with high economical impact (European Commission, Research, technology and innovation 2019).

The requisite to establish this multidisciplinary program is clear, and the perceived progress in society requires active contribution from future-minded scholars with above-mentioned broad qualifications. Thus, it is worth to contribute in conducting the required higher education level, where the multidisciplinary bachelor program is the completeness that should being fully supported. The program is also expected to stimulate intensely productive environment, a condition which is required in developing frontier sciences and their engineering implementations. Additionally, further support from the international accreditation council will bring the program into readiness to cope with the international competitiveness (Shawer 2013).

The bachelor program of engineering physics equips students with a strong grasp of basic sciences (particularly in physics and mathematics) as well as in depth mastery on the broad foundations of engineering concepts. Some examples are listed as in the following:

1. Bachelor of Science (BS) in Engineering Physics, UC Berkeley; offers an interchange classical and modern physics as well as chemistry and mathematics with their engineering applications. It is stated that the solid base in physics and mathematics will provide flexibility to graduates in diverse and complex problem faced by society (Berkeley Academic Guide 2019).
2. Bachelor of Science (BS) in Engineering Physics, Cornell University; offers a deeper understanding of rapidly changing technology based on the strong background of physics and mathematics which is mapped into engineering context. The program will stretch the mind with the basic physics underlying engineering developments with strong mathematical tools (Cornell Engineering 2019).
3. Bachelor of Science (BS) in Engineering Physics, New Hampshire University; offers a balance of physics courses with careful selections of various engineering disciplines. The program focuses more on the fundamental physics and provides flexibility between core and elective courses for students with convenient advising (University of New Hampshire 2019).
4. Bachelor of Science (BS) in Engineering Physics, The University of Tulsa; provides the scientific foundations as well as engineering knowledge which the graduates will obtain the flexibility to work in physics and engineering positions or pursuing graduate studies in physics or engineering (The University of Tulsa 2018).
5. Engineering physics major, Stanford University; provides strong foundations in physics and mathematics in engineering context with problem solving skills. The graduates are prepared solve multidisciplinary area at the forefront of 21st century technology. They are also well prepared to pursue further study in physics or engineering (Stanford Engineering Magazine 2019).
6. Bachelor of Science (BS) in Engineering Physics, Institut Teknologi Bandung; emphasizes on the physics-based subjects and engineering expertise which opens the opportunity for graduates to take a bigger role in problem solving (Engineering Physics ITB).

Therefore, it is clear that graduates are then expected to be capable to think systemically in order to provide integral solutions to the faced technological problems in their society. So the role to bridge-the-gaps between the study of science and engineering is brought in this early level of higher education, which is hoped to improve the acceleration as well as efficiency to many engineering implementations in industrial and business sectors.

THE PROPOSED CLUSTERS OF SUB-DISCIPLINES

Philosophically, the establishment of higher education programs in many countries is intended as a vehicle for further scientific developments, which requires intense and sustained connections among students, professors, peers, colleagues from other fields, and laboratory technicians. These connections are aimed as a learning medium for character and expertise building (Roberts 2015). Problems related to scientific and ethical issues will trigger direct impacts to the surrounding communities and humanity in general. Historical records have shown that many breakthroughs in scientific and technological developments were created by the broadened minds, i.e. the ones who used to think critically and questioning their minds. So for example, it is rather difficult to imagine that Newton established the law of dynamics without prior invention of calculus, the formulation of the law of photoelectric without prior understanding on classical thermodynamics, or as engineers establishing the finite element method if the ancient wisdom of squaring the circle was not considered.

In the proposed bachelor program, mutual interactions will be developed among various competencies and number of expertise that are owned by each cluster of research groups in the department. Such a fused and blended of competencies is necessary to solve many complex engineering problems, as well as to stimulate the emergence of new innovations. It is also intended to function as a vehicle for further developments of new viewpoints in solving many scientific and engineering problems, especially when reliable solutions are put in high priority due to economic and defense reasons. It is thus very important to cluster prioritized focus areas in the curricula and related learning outcomes. These areas should also facilitate flexibility to students in blending interdisciplinary subjects which are suitable to give strong foundations to their chosen comprehensive topics.

Detailed descriptions of the proposed focus areas are derived from the above-mentioned global trends in the 21st century developments of science and technology. Schemes of interaction mechanisms of scientific inter- and multidisciplinary co-operations across fields are proposed as follows:

1. *Field of Photonics Engineering:* Photonic engineering is the field of wave/light photon utilization in various technologies and applications. According to The Optical Society (OSA) the field of optics/photonics can be grouped into 36 major categories and about 1100 sub-categories. Based on these categories, in the field of photonic engineering, the research development is contained in three research groups, i.e.:
    a. Research group of photonic device
    b. Research group of optical metrology and instrumentation
    c. Research group of biomedical optics/biophotonics
    d. Scientific development of photonic devices in the next 10 years will be driven by the needs for devices in optical communication systems/optical signal processing systems that are faster, larger capacity, integrated, and more energy-efficient.
    e. The following are challenges in the field of science of photonic devices that will be studied:
    f. Integration of photonic devices into electronic chip systems. Currently the chip size of modern electronic transistor chains is around 40 nm, while the size of the photonic device channel is 10 times larger than the electronic channel. Attempts to reduce the size of equivalent photonic devices will be able to create the integrated devices with higher communications and signal processing capacities.
    g. Integrated overall optical signal processing. Optical signal processing through electronic-optical-electronic signal conversion has a speed much smaller than the speed of the optical signal/light. The increased signal processing speeds is generated when signal conversions can be avoided, thus the overall signal processing are in optical domains.
    h. Developments of various methods to quantify changes in optical characteristics of biological tissues, i.e. implementing computational as well as experimental measurement approaches. For the computational approach, the golden standard of Monte Carlo algorithm is implemented to simulate the characteristics of light propagation inside biological tissues, i.e. for various tissue conditions as well as parameters of incoming light waves. Simulation by incorporating the fluorescence and tissue polarization states will also being considered as future interesting research topics, as can not being recently implemented due to availability of computational platform. Outcomes of these studies are for the development of novel techniques applicable for various biomedical applications (for diagnostic as well as therapeutic) which are also potential to be implemented for other non-biomedical applications.
2. *Field of Instrumentation and Control Engineering*: Engineering Instrumentation is a specialization focusing on the principle and operation of measuring tools used in the design and configuration of automated systems. To maintain parameters in a process or in a particular system, devices such as microprocessors, microcontrollers, or PLCs are applied. This field is closely related to industry with automated processes, aimed to improving system productivity, reliability, security, optimization, and stability. The study and investigation of various instrument systems (hardware and soft sensors), as well as control strategies are conducted to improve the performance and efficiency of process controls.
3. C. *Field of Energy and Environmental Engineering*: The group will develop science and technology related to the exploitation of the basic concepts of transport phenomena for the purposes of improving performance,

energy conservation and savings associated in industry and buildings. The themes in this field can be grouped into two research lines:

a. Research group of transport phenomena, and
b. Research group of renewable energy technology
c. The research group of transport phenomena studies thermodynamics, fluid mechanics and heat transfer phenomena. The study includes the influence of different geometric applications, which is solved by the computational fluid dynamics (CFD) as a very reliable tool in the development engineering design and applications. The group of renewable energy technology studies the exploration of renewable energy sources, which improve the performance of cascade and turbine farms for the wind, micro-hydro and sea currents. Hybrid power system potential is also investigated as well as off-grid electrical power generation systems for areas with difficult topographic characteristics.

4. *Field of Vibration and Acoustics Engineering*: The emphasis is on the identification of vibration characteristics, monitoring, and handling, as well as various acoustic wave propagation issues in underwater (for navigational purposes) and in human auditory organs.
5. *Field of Material Engineering*: The research on materials development in the last 10 years was focused on the development of light alloys, which requires an understanding of complex precipitation, and its hardening methods. The next is development of intermetallic materials in the process fabrication of superconducting (Nb-Sn) cables, artificial bone implants (Co-Cr), as well as high temperature resistant materials instead of steel (aluminide). Fabricating the metallic oxide nanoparticles for the manufacture of organic solar cells (stimulated by the raising issues of environmental and national energy resilience) is also studied.

The above mentioned cluster groups are highly recent novel research themes which is suitable for the bachelor program in engineering physics, as also being actively developed by many other world-class research groups. The inherent characteristics of these cross-scientific and integrative scientific disciplines will enable students and academic staffs to actively engage in advanced research topics as described above. These passionate and optimistic academic as well as research activities done in this bachelor program in studying and contributing to the above research fields will of course support higher education and research in the underdeveloped and developing countries, which will eventually elevate the competitiveness of these countries equal to other already developed countries.

In order to enhance the cross co-operations among the clusters, it is mandatory to introduce prerequisite courses in the curricula. The course should introduce and nourish students to the awareness for further deepen and grasp the scientific methods. These proposed courses are:

1. *Research Methodology and Scientific Writing*: The course is more than just experimental method which is delivered in the traditional engineering disciplines. In this lecture, the students study the paradigms underlying the research methods in general, basic concepts of research, research stages and types of research which is developed according to its purpose and usefulness. In this course students gain advanced knowledge and ability to conduct and develop research using scientific procedures, i.e. theoretical, empirical, quantitative, or qualitative. This course also requires students to study a more in depth research stages, i.e. preparation, experimental set-up, data collection, data processing and analysis, and presenting research results: either in writing or oral.
2. *Philosophy and Ethics in Science and Technology*: The establishment of science stood on three basic foundations: i.e. ontology, epistemology and axiology. All of these are often forgotten in the modern science and engineering educations. These three foundations become one of the main subjects in this course, in addition to other learned subjects: i.e. knowledge and science, sources of knowledge, theories of truth, the scientific requirements for exploring truth, relationship and socio-economic impact. This lecture builds intellectual awareness through in-depth analysis to the historical progression of science since the age of Ancient Greece, Arab, Renaissance, up to our modern world. By completing this lecture, students will understand historical threads and the spirits behind the development of science in maintaining the sustainable human living.

CONCLUSION

The bachelor program in engineering physics is a multifaceted engineering discipline, i.e. the one with more integrative and systemic approaches, in comparison to other classical engineering disciplines. The emphasis of the program is to prepare students in adapting to future rapidly changing technologies, as well as contribute in solving various complex engineering problems. The program is designed to produce graduates with inherent characteristics, i.e. being able to develop innovative ideas in investigating the complex processes, and providing integrative solutions by incorporating insight into broad area of science and engineering foundations.

The proposed study program focuses more on the latest scientific aspects, considering the strength of available resources in underdeveloped and developing countries. Examples of leading areas include the developments of intelligent optical devices for various physical sensing applications, photonics and biomedical optics, energy systems, smart vibration control, underwater acoustics, hearing aids related technologies, advanced-materials related technologies, and intelligent systems for exploration of renewable energy potentials. They are all designed to be synergistic and cross-cutting from several subfields in physics and engineering disciplines.

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