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CLIMATE CHANGE EDUCATION FOR MITIGATION AND ADAPTATION IN ENGINEERING

Abstract: *Climate change mitigation and adaptation represent two basic strategies in the fight against climate change and two basic directions of modern education for climate change. Engineers, as creators of new technologies and solutions in various fields, have an inevitable impact on climate change, but at the same time, they can contribute to solving this significant problem. For this reason, climate change education of engineers is an imperative of modern times. The work is aimed at elaborating the need for climate change education of engineers, identifying ways of integrating climate change into the curriculum, as well as understanding the challenges and problems accompanying the integration and implementation of climate change education in engineering. In addition, the paper aims to map courses on climate change in the current higher education engineering curricula in Serbia.*

Keywords: climate change education, climate change mitigation, climate change adaptation, engineering

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INTRODUCTION ON CLIMATE CHANGE EDUCATION

Increasingly extreme weather events, rising temperatures, melting glaciers and rising sea levels, increasing droughts, as well as heavy rainfall and floods, etc., are clear indicators of climate disruption on Earth, with accompanying negative effects. This is why climate change is often described as a “super-wicked”[1] problem in the literature. Life in a changed climate has caused the need for adaptation to the newly created conditions, but also the necessity of mitigating the consequences of climate change in the future. This led to the need for education in this area. As an important element in the fight against climate change, climate change education is becoming a basic tool for addressing it. This is also confirmed by the UNICEF survey (2023), according to which, on average, 85% of young people from 55 countries, aged 15-24, pointed out that they have heard about climate change, but only half of them know what climate change actually is.

Climate change education can be described as education that helps people understand and address the impacts of the climate crisis, empowering them with the knowledge, values and attitudes needed to act as agents of change[2]. These efforts can be accomplished through: enriching the fund of knowledge on causes and effects of climate change; facilitating the understanding of consequences of climate change; developing skills to consider complex issues and think critically; cultivating skills necessary to take action; as well as changing behavior and attitudes towards more sustainable lifestyles[3]. Universities, which are becoming the so-called “climate change agents” have shown support in implementing the previous actions. On the one hand, they are striving to become “carbon neutral” institutions when it comes to their operational practices, while on the other hand, they are developing their curricula and pedagogical approaches to educate students (and society) about the imperatives of carbon neutrality and climate change mitigation and adaptation. Therefore, the role of universities becomes crucial when it comes to educating future

[1] The term “wicked” was created in 1973 based on the idea of researchers Rittel and Webber, who used it to denote problems that persist because they are difficult to solve (Hald-Mortensen, 2023) due to reasons such as: time to find a solution is running out; there is no central authority to manage the problem; those causing the problem are those who can contribute to its resolution; the problem is long-term and large-scale, so any short-term improvement can be considered inadequate. As climate change consists of numerous sustainability-related wicked problems, such as biodiversity crisis, climate migration, etc., it becomes a super-wicked problem (Cambridge & Cambridge ZERO, 2024).

[2] Climate Change Education, https://www.unesco.org/en/climate-change/education

[3] What is climate change education?, https://cambridge-community.org.uk/professional-development/gswcce/

environmental auditors, community organizers, corporate managers, engineers, practitioners, technical professionals, policy makers, and the entire community about actions that can be taken in the field of climate change mitigation and adaptation (Leal Filho et al., 2021).

Here, engineering professions stand out as particularly important. Namely, the engineers of the future "play an urgent and pivotal role in sustainable growth, technological development, and environmental regeneration, with all sectors of engineering working inclusively and across fields. Engineers are demonstrating leadership, creativity and technical excellence by implementing solutions that shape the future and enable society to navigate immediate challenges" (NEPC & Royal Academy of Engineering, 2024b), as that of climate change. The role of engineers in this field and the need for climate change education for mitigation and adaptation in engineering are presented below.

ENGINEERS AND CLIMATE CHANGE: THE NEED FOR EDUCATION

The connection between engineering and climate change can be described as two-sided: engineering is both the cause of the problem and its solution. Namely, numerous aspects related to engineering, e.g., traffic, factories (machinery and tools), households (devices, appliances, etc.) are also the main emitters of carbon dioxide, contributing greatly to the problem of global warming and, consequently, to climate change. On the other hand, innovative engineering solutions[4] help our vehicles, production processes, homes, etc. become more carbon neutral, that is, more sustainable, thereby contributing to solving the problem of climate change. More precisely, the role of engineers in addressing climate change involves two aspects: mitigation and adaptation. Their difference is highlighted by McCowan (2021), stating that mitigation refers to the reduction or prevention of the causes of climate change, primarily the emission of greenhouse gases, while adaptation implies necessary changes in relation to climate change impacts, i.e. ensuring the survival and well-being despite the challenges. As engineers are "immediate inventors and implementers of new technologies, harnessing raw materials, and using energy both at the construction stage and throughout their operational life" (Axelithioti et al., 2023, p. 3), their role in mitigating the causes of climate change is obvious. When it comes to climate change adaptation, their role can be observed through the practices of responding to increasingly severe weather events and sea level rise. For example, engineers are expected to reinstate critical infrastructure[5] through disaster recovery and risk management (Axelithioti et al., 2023).

As pointed out by Molthan-Hill et al. (2019), implementation of adaptation and mitigation strategies requires capable policymakers and an informed public. Educated people are more aware of the climate change risks and are better equipped to make informed decisions when it comes to responding to climate change at the local, national and international level. Therefore, the answers to the aforementioned challenges in engineering can be sought and found in engineers' climate change education for mitigation and adaptation, or, more precisely, in the reshaping of engineering education, and the need to react in this field can be labeled as "urgent". This urgency stems from the fact that the consequences of climate change are becoming more and more obvious and massive, and the temperature rise is constant. Also, there is a fact pointed out by Martin et al. (2022), that "engineers beginning their education in 2022 will practice into the 2060s or beyond, and the impact of their decisions will be seen well into the 22nd century" (p. 744). Unless sustainability and resilience become part of engineering designs today, engineering will continue to have a negative impact on the climate for decades, requiring expensive modifications to achieve resiliency. To sum up, the climate crisis is happening right now, and we cannot wait for a new generation of engineers to be trained (Martin et al., 2022) in the field of "education made to measure" climate change. It is necessary to integrate climate change in all possible aspects of the formal education system, while also applying the rule of continuous learning and improvement (lifelong learning) for engineers who are outside the formal system - in practice. Also, as Amarquaye (2024) points out, upskilling[6] becomes particularly important in encouraging talent mobility, allowing engineers to easily move across sectors, such as academia, industry and government.

[4] For example, environmental protection engineers are focused on designing products and systems for air and water purification; civil and mechanical engineers can contribute to reducing our impact on the environment by changing and designing new materials used in modern technologies; engineers also create and use alternative sources of energy such as geothermal, solar or biomass energy, which slows down greenhouse gas emissions (Climate Change, https://www.teachengineering.org/populartopics/view/climatechange).

[5] The existing infrastructures are based on historical climate data that support the assumption of a stable climate. However, due to rising sea levels and increasingly frequent extreme weather events which have been happening in recent history, this assumption has been called into question (Higgs & Patil, 2024).

[6] The term upskilling refers to the acquisition of additional/new skills, i.e. improvement of existing ones. According to Gillis (2024), upskilling is a workplace trend that provides training programs and development opportunities to expand an employee's abilities and minimize skill gaps.

CLIMATE CHANGE AND ENGINEERING CURRICULUM: INTEGRATION, IMPLEMENTATION, CHALLENGES

Integrating climate change education for mitigation and adaptation into engineering curricula is not a simple task at all. Namely, climate change education cannot be reduced only to acquisition of a series of facts, but also requires the development of practical skills, adherence to values relating to humanity and nature, changes in lifestyles and collective modes of organizing, which can be particularly challenging. Also, students must be trained to critically and autonomously examine the evolving debates and evidence about climate, rather than passively adopting "neatly packaged" knowledge and beliefs. In addition, each student comes to the classroom with a set of existing knowledge, capacities and attitudes about climate, and already faces the challenges of climate change in their daily lives (McCowan, 2021). It is important to note that students' current attitudes on climate can be very extreme, based on wrong assumptions, and even on distrust in human-caused climate change (Higgs, 2024, according to Milovanovic et al., 2022; Shealy et al., 2017). Also, very often students cannot see the connection between their future profession and climate change and environmental problems (Axelithioti et al., 2023). The integration and implementation of climate change education are also accompanied by problems related to uncertainty regarding the best way to integrate climate change issues into the curriculum, resistance to the introduction of such content, on account of the contested values involved and the lack of expertise of the teaching staff (McCowan, 2021). Furthermore, if climate change were to become a part of the curriculum as a course/module, other issues regarding their status would ensue - should such courses be compulsory for all students, to ensure that every student is introduced to this key issue? It is also necessary to mention the principle of such courses' electability. There are constraints on universities as institutions in compelling students to engage in particular activities, given that the learners in question are normally adults who have freely chosen to study there. Also, if courses are compulsory, but not directly connected with disciplinary content, they might not be taken seriously and even cause resistance among students. In addition, questions of "space" in the curriculum are raised, because climate change, in a way, competes with other important topics such as peace, global health, human rights and citizenship (Ibid).

When it comes to the ways of integrating climate change into the curriculum, as in the case of any topic, climate change can become a part of already existing courses, with an effort to connect the contents of those courses with climate change, but it can also be studied as a separate course whose contents would fully cover the issues and problems of climate change. Also, entire faculty programs can be devoted to climate change. Molthan-Hill et al. analyzed the ways of integrating climate change into university curricula (2019), and singled out the following approaches:

(1) *Piggybacking* – adding climate change to existing courses or modules;
(2) *Specializing* – creation of separate modules, courses or programs;
(3) *Mainstreaming* – integration of climate change throughout the curriculum;
(4) *Connecting (transdisciplinary)* – designing new cross-disciplinary offers, such as a course on climate change that would be common to all students of one university/faculty, and within which teaching materials from different disciplines would be integrated.

Regardless of the mentioned challenges and the ways of integrating climate change in the curriculum, it is required that it must contribute to the development of certain skills of engineers in the field of climate change, with adequate didactic and methodical practices[7]. More precisely, the education of engineers for climate change should be implemented by engaging students with real-world problems, e.g. through case studies and open access digital tools, in order to develop skills such as multidisciplinary and systems thinking, as well as through hands-on experiential learning, which provides a space for creativity and the ability to connect theory with practice (Casciato, 2024). In addition, engineers must be equipped with skills such as critical thinking that will help them develop problem solving and design thinking capabilities (Ibid); technical competencies such as data analysis, project management; as well as soft skills like creativity, adaptability, collaboration, and effective communication to facilitate the transfer of information about the societal and economic impacts of climate change to industry leaders, policy makers and the public (Amarquaye, 2024). Furthermore, engineers are required to be "socially aware and ethically minded, resilient and innovative" (Cambridge & Cambridge ZERO, 2024, p. 2).

An interesting set of engineering skills is provided by Martin et al. (2022), who state that the following four

[7] According to graduate engineering students (NEPC & Royal Academy of Engineering, 2024a), a greater and more consistent integration of real-life professional experience into the curriculum and development of professional skills can be achieved through: collaboration with industry and community partners (e.g. visits, guest lectures, mentorships, etc.); active learning (real-life projects, collaborative learning, case studies); exposure to interdisciplinary practices (integrated coursework, group projects, cross-departmental collaboration); shifting towards more flexible and student-centered degrees (emphasis should be on motivating students to be more active through various projects, reduction of teaching-centred content delivery, possibility of choosing courses in accordance with future professional interests or narrower specialization); emphasizing lifelong learning and continuous professional development.

skills are most readily identifiable as necessary in engineering:

(1) *An understanding of climate, sustainability, and resilience linked to engineering design* – understanding the essence of climate and climate impacts; taking climate adaptation into account when considering the impact of climate change on the performance of their systems and designing for resiliency in response to increasingly frequent climate events; consideration of long-term climate change mitigation; understanding how the functionality and performance of technology and infrastructure change in the conditions of a changing climate, etc.;

(2) *An ability to incorporate knowledge from a range of scientific disciplines into engineering solutions* – the need for engineers to cooperate with ecologists, biochemists, biologists, epidemiologists, experts in the field of public health, etc. conditions change in how they are educated in biological, ecological and life sciences, as well as how they develop skills needed for successful communication and cooperation with different scientific communities;

(3) *Understanding the ethics and justice dimensions of engineering* – without an ethical framework, engineers can create solutions whose costs and benefits are unequally and even unethically distributed, causing harm to certain communities[8]; it is especially important to understand the concepts of environmental justice and energy equality (in order to incorporate these concepts during the development and deployment phase in a way that addresses the entire life cycle of systems);

(4) *Listen to and collaborate with diverse communities* – the ability of engineers of all backgrounds to work with underrepresented communities (such as non-white), respecting embedded community knowledge, connecting their solutions with the experiences and knowledge of local communities, etc.

METHODS

The aim of the research is to map study programs and courses dedicated to climate change at the universities and faculties of the Republic of Serbia. For that purpose, a desktop analysis of available data on the official websites of engineering faculties in Serbia, including both state and private institutions, was used. The following universities/faculties were included in the analysis: University of Kragujevac (Faculty of Engineering, Faculty of Mechanical and Civil Engineering, Faculty of Agronomy in Čačak, Faculty of Technical Sciences in Čačak); University of Novi Sad (Faculty of Technical Sciences, Faculty of Agriculture, Faculty of Technology, Mihajlo Pupin Technical Faculty); University of Belgrade (Faculty of Architecture, Faculty of Civil Engineering, Faculty of Mining and Geology, Faculty of Agriculture, Faculty of Forestry, Faculty of Mechanical Engineering, Faculty of Transport and Traffic Engineering, Faculty of Technology and Metallurgy, School of Electrical Engineering, Technical Faculty in Bor); University of Niš (Faculty of Occupational Safety, Faculty of Agriculture in Kruševac, Faculty of Civil Engineering and Architecture, Faculty of Electronic Engineering, Faculty of Mechanical Engineering, Faculty of Technology in Leskovac); University of Prishtina (Faculty of Technical Sciences Kosovska Mitrovica, Faculty of Agriculture and Veterinary Medicine); Megatrend University (Faculty of Biofarming Bačka Topola); Alfa BK University (Faculty of Information Technologies); University Business Academy in Novi Sad (European Faculty “Kallos” Belgrade, Faculty of Economics and Engineering Management in Novi Sad; Faculty of Applied Sciences in Niš); University Metropolitan (Faculty of Information Technology, Faculty of Management); Singidunum University (Faculty of Informatics and Computing); Union University Belgrade (School of Computing); State University of Novi Pazar (engineering study programs such as Architecture, Agronomy, etc.); University of Criminal Investigation and Police Studies (study program Forensic Engineering); Educons University (Study program of Information Technology and Faculty of Ecological Agriculture); University “Union Nikola Tesla” (Faculty of Construction Management); MB University (Faculty of Business and Law).

The analysis was based on the key term “climate change”, i.e. the intention was to identify only those study programs and courses that contain the term “climate change” in their title. Therefore, courses whose title contains terms “climate”, “climatology”, etc., and whose contents include broader topics that may be, but are not necessarily related to climate change, were excluded from the analysis. One study program, i.e. module, and 24 courses were identified.

RESULTS

Study programs on climate change

The analysis of study programs at engineering faculties in the Republic of Serbia showed that no study program contains the term “climate change” in its title. However, the master’s academic study program of the Faculty of Agriculture in Novi Sad “Soil, plant and genetics”[9] contains an elective area, i.e. module entitled “Climate smart agriculture”. This study program was accredited in 2021, and in addition to the

[8] For example, while nuclear power plants reduce greenhouse gas emissions, three quarters of total uranium production comes from mines in or near Indigenous communities. After the production process is completed, mines are often left unremediated, which leads to land and people poisoning, while impacting traditional ways of life (Martin et al., 2022, according to Verma & Djokic, 2021).

[9] http://polj.uns.ac.rs/sr/node/3163

aforementioned, it contains eight more modules dedicated to soil, plant cultivation and nutrition, irrigation, genetics, etc. The module "Climate smart agriculture" aims to "educate and train students for a better understanding and mitigation of the harmful effects of extreme weather conditions and climate change in agriculture" [10]. The Module equips students with competencies for designing original solutions in order to mitigate/eliminate the negative consequences of climate change, planning the production and protection of plants according to the expected effects of climate change, using publicly available results of weather and climate simulations, etc. [11]

In the first semester, the Module contains three compulsory courses: Principles of experimental work, Climate change and extreme weather events, and Physiological responses of plants to changes in environmental factors. In addition, students choose two of the six elective courses offered: Climate change and insects, Modeling in plant production and plant protection, New technologies, Climate change adaptation measures in crop production, Soil and management measures for climate change adapted agriculture, Irrigation and climate change. The second semester is devoted to writing a master's thesis. Module courses that contain the term "climate change" in the title are also given in Table 1.

Courses on climate change

Courses that contain the term "climate change" in their title are presented in Table 1. Course traits – status (compulsory or elective), level of studies and year of studies (in the case of undergraduate academic studies) are also given in Table 1.

Table 1. *Courses on climate change at engineering faculties in Serbia*

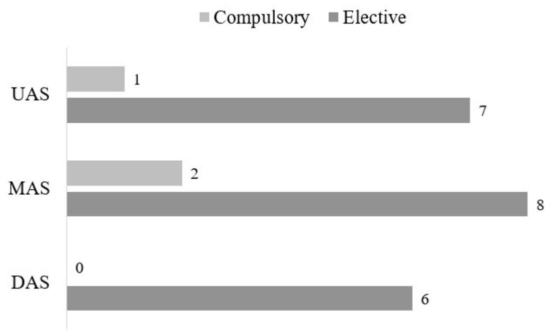
University	Course name	Course traits
University of Kragujevac		
Faculty of Engineering[12]	Engineering and cc	E/UAS, IV
University of Novi Sad		
Faculty of Technical Sciences[13]	Energy efficiency of buildings and cc	E/DAS
Faculty of Agriculture[14]	Cc and extreme weather events	C/MAS
	Cc and insects	E/MAS
	Cc adaptation measures in crop production	E/MAS
	Soil and management measures for cc adapted agriculture	E/MAS
	Irrigation and cc	E/MAS
	Forest ecosystems and cc	E/DAS
	Modeling of forest ecosystems and cc	E/DAS
University of Belgrade		
Faculty of Agriculture[15]	Agriculture and global cc	E/UAS, IV
	Cc and adaptation	E/MAS
	Cc and fruit tree adaptation	E/MAS
	Cc and food	E/DAS
Faculty of Forestry[16]	Climate disaster risk management and cc	E/UAS, III
	Cc and forest ecosystems	E/UAS, II
	Cc and forest ecosystems	E/DAS
	Vegetation and cc	E/MAS
University of Niš		
Faculty of Occupational Safety[17]	Adaptation to the effects of cc	E/MAS
Faculty of Agriculture in Kruševac [18]	Adaptation measures to cc in agricultural production	C/MAS
Faculty of Civil Engineering and Architecture [19]	Construction and cc	C/UAS, I
	Adaptation to cc	E/UAS, II
University of Prishtina		
Faculty of Technical Sciences Kosovska Mitrovica [20]	Adaptation to the effects of cc	E/UAS, III
Educons University		
Faculty of Ecological Agriculture[21]	The impact of cc on agricultural production	E/DAS
State University of Novi Pazar		
Agronomy[22]	Crop production and cc	E/UAS, III

Notes: cc – climate change; E – elective course; C – compulsory course; UAS – undergraduate academic studies; MAS – master academic studies; DAS – doctoral academic studies; I-IV – year of studies (for UAS courses)

As shown in Table 1, courses on climate change are represented at all state universities, as well as at two

[10] http://efaidnbmnnnibpcajpcglclefindmkaj/http://polj.uns.ac.rs/sites/default/files/upload/ЗЕМЉИШТЕ%2C%20БИЉКА%20И%20ГЕНЕТИКА%20НОВО.pdf
[11] Ibid.
[12] www.fink.rs
[13] www.ftn.uns.ac.rs
[14] http://polj.uns.ac.rs
[15] http://www.agrif.bg.ac.rs/
[16] www.sfb.bg.ac.rs
[17] www.znrfak.ni.ac.rs
[18] https://poljfak.ni.ac.rs
[19] www.gaf.ni.ac.rs
[20] https://ftn.pr.ac.rs/
[21] https://educons.edu.rs/
[22] https://www.dunp.np.ac.rs/

private universities. However, the resulting number of faculties is very small in relation to the total number of faculties, i.e. programs related to engineering sciences. Most courses belong to the field of agriculture, followed by forestry. The representation of courses by their status and level of studies is given in Figure 1.



Notes. UAS – undergraduate academic studies; MAS – master academic studies; DAS – doctoral academic studies

Figure 1. *The representation of courses on climate change by their status and level of studies*

Almost all courses are elective, except for three: Climate change and extreme weather events (Faculty of Agriculture, University of Novi Sad); Adaptation measures to climate change in agricultural production (Faculty of Agriculture, University of Niš); Construction and climate change (Faculty of Civil Engineering and Architecture, University of Niš). The first two courses are a part of the master's academic studies, while the third is the only compulsory course at undergraduate academic studies, as well as the only course on climate change that is taken in the first year of studies. Apart from this course, there are seven other courses at bachelor academic studies, namely: two in the second year of studies; three in the third year of studies; and two in the fourth year of studies. All of them are elective. The largest number of courses belongs to master's academic studies - 10 of them, while 6 subjects are a part of doctoral academic studies.

CONCLUSION

Raising the awareness of the impact of engineering on climate change and successful action in the field of its mitigation, as well as creating innovative solutions for climate change adaptation, requires adequate education, because one thing is certain: "If education is a preparation for life, then inescapably it must address the challenges of climate change" (McCowan, 2021, p. 3).

Universities, recognized as climate change agents, are incorporating it into their curricula in different ways - as part of existing courses or by creating special courses, as well as study programs in this field. Although this integration is accompanied by many challenges, such as difficulties in finding the connection between certain contents and climate change, insufficient training of teachers for the successful delivery of such contents, lack of "space" in the already overcrowded curricula, etc., the conclusion is clear - the challenges must be overcome, because engineers facing climate change already need skills such as systemic and critical thinking, creativity, collaboration, project management, data analysis, etc.

The analysis of the curriculum at engineering faculties in the Republic of Serbia showed the following:

- Only one study program, i.e. module, entirely dedicated to climate change was identified, at the Faculty of Agriculture of the University of Novi Sad;
- There are courses on climate change at all state universities, as well as at two private universities; however, it is a very small number of faculties, that is study programs, that offer such courses;
- Most courses belong to the field of agriculture, followed by forestry;
- Almost all courses are elective;
- The largest number of courses are a part of master's academic studies.

Finally, it is important to point out two "critical points", i.e. challenges, that require special attention:

- Most of the existing courses on climate change belong to the fields of agriculture and forestry, which further leads to the conclusion that the programs of many engineering fields, such as traffic, environmental protection, mechanical engineering, construction, etc., do not have courses fully dedicated to climate change. Consequently, this can lead to the inability to see the connection of one's profession with climate change clearly, and to the complete neglect of climate change in practice.
- Also, when it comes to existing courses, a big problem is that they are mostly elective, which means that students who do not choose a course on climate change are once again deprived of the possibility of a deeper connection of their profession with the climate change issues.

However, this does not mean that climate change content at other engineering faculties has been completely neglected. For future research, it is recommended to analyze all courses (except those that contain the term "climate change" in their title) of all engineering programs, in order to determine the representation of climate change as part of the teaching content.

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