Geosynthetics in the classroom: Educating future engineers and their instructors

J.G. Zornberg

University of Texas at Austin, Austin, Texas, USA
zornberg@mail.utexas.edu

ABSTRACT: Geosynthetics—synthetic geomaterials—have become essential in geotechnical engineering, yet their coverage in undergraduate civil engineering curricula remains limited. This paper addresses this educational shortfall by proposing a teaching framework that parallels the instruction of geosynthetics with that of soils, promoting a more cohesive understanding of geotechnical materials overall. The approach emphasizes introducing geosynthetics early in the curriculum, especially as part of the introductory geotechnical engineering course. This strategy aligns with the International Geosynthetics Society's global initiative to support faculty in incorporating geosynthetics into their teaching. The paper also presents results from an international faculty survey across nine countries, revealing the typical structure of geotechnical education and the limited inclusion of geosynthetics, which are often confined to electives or brief mentions. Findings show that, although geotechnical engineering is generally a required subject—particularly outside the United States—, instruction on geosynthetics remains uncommon. This gap can be effectively addressed through targeted educational strategies that introduce geosynthetics in a way that reinforces core geotechnical concepts while emphasizing the vital role of geomaterials as construction materials. These insights highlight the importance and feasibility of integrating geosynthetics into the core civil engineering curriculum to better prepare graduates for modern engineering challenges.

Keywords: Undergraduate Education, Geosynthetics, Survey, Curriculum

1. Introduction

Geosynthetics have become essential materials in contemporary geotechnical engineering practice, offering innovative, cost-effective, and sustainable solutions for a broad range of infrastructure challenges. Despite their widespread use, instruction on geosynthetics remains largely absent from undergraduate civil engineering programs. A key reason for this absence is that many current faculty members were not exposed to geosynthetics during their own academic training, given that the field has only matured in recent decades. This generational gap has contributed to the persistent exclusion of geosynthetics from core civil engineering curricula.

Incorporating geosynthetics into undergraduate education may present significant challenges. A key obstacle is the curriculum: Civil engineering programs face growing demands to cover a broader technical knowledge within limited credit hours. Faculty must make tough choices about which topics to include, often favoring traditional subjects over newer ones. Although geosynthetics are now recognized as essential geomaterials used in nearly all areas of geotechnical engineering, they are frequently overlooked in undergraduate instruction.

Another significant obstacle is the lack of faculty preparedness. Since many geotechnical educators were not taught about geosynthetics themselves, they might feel unprepared to introduce this topic in their courses. While continuing education and professional training can address practical applications, it can be argued that instruction on the fundamental behavior of geosynthetics belongs earlier in the learning process, alongside foundational topics such as the mechanical and hydraulic properties of soils.

Integrating geosynthetics into the introductory geotechnical engineering course offers a strategic approach. This can be achieved by framing geosynthetics as part of the broader family of geomaterials, which includes both natural and synthetic materials used in geotechnical engineering. Notably, geomaterials can be studied not only as existing materials that remain in place to support infrastructure (e.g., foundation soils), but also as construction materials actively used to build the infrastructure itself, such as embankments, dams, or roads. Introducing geosynthetics within this construction-materials framework helps students develop a unified understanding of how different materials contribute to engineering performance, from both a foundational and structural standpoint.

Meaningful exposure to geosynthetics in undergraduate civil engineering programs can be achieved with minimal disruption to the curriculum. Even brief, well-integrated instruction—such as a single lecture—can serve as a starting point. This paper supports that premise by offering a structured framework to help incorporate geosynthetics into core geotechnical education. It begins with a basic overview of geosynthetics, including their classification by type and the engineering functions they perform. This establishes a shared instructional vocabulary and highlights opportunities to integrate geosynthetics alongside traditional geomaterials.

As part of this paper's preparation, an international survey was created and distributed, and its results were analyzed to evaluate the current state of undergraduate geotechnical education in selected countries. The results provide insights into the structure of geotechnical courses, the limited focus on geosynthetics, and regional differences in curriculum emphasis.

The paper also describes the International Geosynthetics Society (IGS)'s “Educate the Educators” (EtE) initiative, which offers faculty instructional resources and training to help incorporate geosynthetics into existing courses (Zornberg et al., 2020; Gardoni et al., 2024).

Additionally, the paper details specific educational strategies that align the teaching of geosynthetics with fundamental geotechnical concepts. These include introducing geosynthetics early as construction materials, emphasizing their parallels with soil behavior, and drawing on their distinct two-dimensional characteristics to reinforce key mechanical and hydraulic principles. Instructors are encouraged to revisit the topic of geosynthetics in subsequent courses as applications are examined, enhancing students’ conceptual continuity.

By integrating survey data on the state of geotechnical education, technical content, institutional context, and pedagogical strategies, the paper provides a practical model for incorporating geosynthetics into undergraduate teaching, helping to ensure that future civil engineers are equipped to work with both traditional and emerging construction materials.

2. An Overview of the Basic Content on Geosynthetics

2.1. General Overview

Geosynthetics are synthetic materials used in geotechnical engineering applications to enhance civil infrastructure's performance, durability, and sustainability. Their use has evolved significantly since the 1960s, when geotextiles were first deployed in filtration and separation roles. Over the decades, the family of geosynthetics has expanded to include geogrids, geomembranes, geonets, geocomposites, and geocells, among others. These products are now routinely used in functions such as separation, reinforcement, filtration, drainage, barrier protection, and erosion control. Their versatility and reliability have made them integral components in the construction of roads, retaining structures, landfills, embankments, and environmental protection systems. This section introduces their classification and performance characteristics. The subsequent sections, 2.2 and 2.3, will define the scope of this paper and further categorize geosynthetics by type and function.

2.2. Types of Geosynthetics

The term “geosynthetics” covers a wide range of synthetic materials used in contact with soil, rock, and other geotechnical engineering-related materials. These products are specifically engineered to perform a variety of functions—such as reinforcement, filtration, and barrier protection—in civil, environmental, and transportation projects. Each type of geosynthetic has unique features that make it especially suitable for specific uses. Understanding the differences among these materials is fundamental for their correct design and application. The main categories of geosynthetics, in the order most commonly used in educational settings, include:

- **Geotextiles** are permeable fabrics, typically made from polypropylene or polyester, that improve soil behavior. They are woven (structured) or nonwoven (felt-like).
- **Geogrids** are open-grid structures formed by polymers, used primarily for reinforcement. Their open configuration allows for soil interlock and transfer of tensile loads, making them effective in applications such as base reinforcement and retaining wall stabilization.

- **Geonets** involve intersecting ribs in a planar setup, usually made from extruded polymers. They mainly drain by enabling in-plane flow, commonly used in landfills and subsurface drainage.
- **Geomembranes** are essentially impermeable polymer sheets used as hydraulic barriers in landfill liners, ponds, and canals to prevent fluid migration.
- **Geosynthetic Clay Liners** (GCLs) are factory-made hydraulic barriers with bentonite clay between geotextiles or bonded to a geomembrane, mainly used as alternatives to compacted clay liners in containment systems.
- **Geocells** are three-dimensional, honeycomb-like structures usually made from high-density polyethylene (HDPE). When filled with soil or aggregate, they offer confinement and distribute loads, making them suitable for slope protection and load support.
- **Geofoams** are lightweight EPS blocks that reduce load on soils. Their low density and easy installation make them ideal for embankments over soft soils and slope stabilization.
- **Geocomposites** are hybrid systems that combine two or more types of geosynthetics—such as geotextiles bonded to geonets or geomembranes—to serve multiple functions at the same time, like drainage, filtration, or acting as a barrier and protective layer.

This classification provides a basic understanding for educators and students alike. The following section will cover the main functions these geosynthetic products are designed to perform.

2.3. Functions of Geosynthetics

Geosynthetics serve a wide range of functions in geotechnical, environmental, and transportation engineering applications. These functions describe the essential ways in which geosynthetic materials interact with surrounding soils and other system components to achieve specific performance outcomes. A single geosynthetic product may perform one or multiple functions simultaneously, depending on its properties and the configuration in which it is used. Understanding these different functional roles is crucial for proper design, specification, and instruction.

The primary functions of geosynthetics, as acknowledged in engineering practice and design guidelines, include (Koerner, 2012; Zornberg, 2017):

- **Separation**: The geosynthetic, placed between two dissimilar materials, maintains them apart to keep their integrity and functionality.
- **Filtration**: The geosynthetic allows water (or other liquids) to flow across its plane while retaining upstream fine soil particles.
- **Reinforcement**: The geosynthetic develops tensile forces intended to maintain or improve the stability of the soil-geosynthetic composite
- **Stiffening** (also known as stabilization): The geosynthetic develops tensile forces intended to control the deformations in a soil-geosynthetic composite.
- **Drainage**: The geosynthetic allows liquid (or gas) flow within the plane of its structure.
- Hydraulic/Gas **Barrier**: The geosynthetic minimizes the cross-plane flow, providing containment of liquids or gases
- **Protection**: The geosynthetic provides a cushion above or below other material (e.g., a geomembrane) to minimize damage during construction or operation

These seven functions are not merely classifications; they are essential to define the relevant engineering properties for a geotechnical project. They are also associated with mechanisms by which geosynthetics contribute to the overall performance and longevity of geotechnical systems. For example, a single geosynthetic layer in roadways may simultaneously provide separation, reinforcement, and drainage. Understanding these functions is essential for helping students recognize the multifaceted role of geosynthetics in civil infrastructure.

3. An International Survey on Undergraduate Geotechnical Engineering Education

3.1. Civil Engineering Undergraduate Education in Representative Countries

Civil engineering undergraduate programs worldwide differ in structure, duration, and emphasis, reflecting the diversity of national educational systems. This section provides a comparative overview of undergraduate civil engineering education in nine countries selected for their representative and contrasting educational models: Argentina, Brazil, Canada, Colombia, Germany, Greece, India, Turkey, and the United States. These countries span multiple continents and higher education frameworks, offering valuable insights into how undergraduate engineering education is organized globally.

Table 1 provides a comparative summary of civil engineering degree requirements across the nine countries. It includes degree duration, type, language of instruction, licensing status, and typical final requirements.

Table 1. Summary of Undergraduate Civil Engineering Education in Selected Countries

COUNTRY	DEGREE TITLE (ENGLISH TRANSLATION)	DURATION	DEGREE TYPE	LANGUAGE	LICENSE REQUIRED?	FINAL PROJECT / INTERNSHIP
ARGENTINA	Civil Engineer	5–6 years	Single-cycle	Spanish	Yes (provincial councils)	Final project, internship
BRAZIL	Civil Engineer	5 years	Single-cycle	Portuguese	Yes (CREA)	TCC (capstone), supervised internship
CANADA	B.Sc. / B.Eng. in Civil Engineering	4 years	Bachelor's	English / French	Yes (provincial boards)	Capstone project, optional co-op
COLOMBIA	Civil Engineer	5 years	Single-cycle	Spanish	Yes (COPNIA)	Final project, internship
GERMANY	B.Sc. + M.Sc. in Civil Engineering	3 + 2 years	Bologna model (3+2)	German	Yes (state engineering chambers)	Thesis, internships common
GREECE	Diploma in Civil Engineering	5 years	Equivalent to an Integrated Master's	Greek	Yes (TEE)	Thesis, design studio
INDIA	B.Tech / B.E. in Civil Engineering	4 years	Bachelor's	English	Optional (state-specific)	Internship often required
TURKEY	B.Sc. in Civil Engineering	4 years (+1 prep)	Bachelor's	Turkish / English	Yes (Chamber of Civil Engineers)	Mandatory internship
UNITED STATES	B.S. in Civil Engineering	4 years	Bachelor's	English	Yes (PE licensure path)	Capstone project, internship encouraged

Despite their differences, civil engineering programs in these countries share a common goal: to prepare students for professional practice through foundational training in engineering sciences, specialized instruction in civil engineering disciplines (e.g., structural, geotechnical, hydraulic, and transportation), and practical experience. However, a major difference lies in the duration of the undergraduate degrees offered. These can be summarized as follows:

- **Four-year programs** are standard in Canada, India, Turkey, and the United States, where students typically earn a Bachelor of Science (B.Sc., B.E., or B.Tech) in Civil Engineering. These programs generally focus on foundational coursework during the first two years, followed by specialization and design-focused courses in the final years. Internships or co-op experiences may be required or highly encouraged.
- **Five-year programs** are standard in Argentina, Brazil, Colombia, and Greece, often structured as single-cycle professional degrees or integrated masters-level diplomas. These programs offer a more comprehensive curriculum, usually including mandatory internships and final thesis projects. In Greece, the five-year Diploma in Civil Engineering is often deemed an integrated master's degree (EQF Level 7). Germany follows the Bologna 3+2 model, where students first earn a 3-year B.Sc., followed by an optional 2-year M.Sc. for full professional qualification. Although technically modular, completing the full five-year cycle is standard for students aiming to become licensed civil engineers.

These variations in duration influence how geotechnical and specialized content, including geosynthetics, is incorporated into the curriculum. For example, five-year programs typically provide more time for detailed coverage of advanced topics or design applications, whereas four-year programs may rely on technical electives or graduate studies to achieve similar depth.

3.2. Characteristics of the International Survey

To better understand how geotechnical engineering—and specifically geosynthetics—is taught at the undergraduate level, an international survey was conducted using the Qualtrics XM platform. The survey targeted civil engineering faculty members across nine countries: Argentina, Brazil, Canada, Colombia, Germany, Greece, India, Turkey, and the United States. These countries were chosen to represent a diverse range of educational models and program structures, as outlined in the previous section.

The survey included a total of 339 respondents out of 466 identified civil engineering programs, resulting in an exceptionally high response rate of approximately 73%. Table 2 summarizes the total number of civil engineering programs identified in each country, along with the number of responding institutions and their response rates. Only one faculty member from each identified academic institution was contacted to complete the survey. The questionnaire was structured into several parts, two of which are evaluated in this paper. The first part gathered general information about undergraduate civil engineering programs, focusing on geotechnical engineering education. It addressed the number of required versus elective geotechnical courses, when these courses are offered during the program, and allows providing information on whether they include laboratory or field components. The second part examined the inclusion of geosynthetics in the curriculum—both as required and elective courses—and gathered input on teaching strategies and perceived challenges.

Table 2. Summary of Survey Responses

Country	# Programs Identified	# Responses	Response Rate
Argentina	22	19	86%
Brazil	56	44	79%
Canada	22	19	86%
Colombia	25	14	56%
Germany	59	28	47%
Greece	7	7	100%
India	49	36	73%
Turkey	97	64	66%
USA	129	108	84%

The survey was designed using closed-ended questions to facilitate comparative analysis, with optional open-text fields allowing respondents to provide more details about specific practices or challenges. Participants were also asked to share information about the institutional context, including program size, degree titles, and country-specific licensing or accreditation requirements. The survey was distributed in English and administered electronically, enabling broad geographic participation with minimal logistical obstacles.

3.3. Structure of the Survey Instrument

The international survey that informed this study was developed and conducted using the Qualtrics XM platform. It specifically targeted university faculty members who teach geotechnical courses and aimed to capture both structural and instructional aspects of the curriculum. The survey gathered geotechnical engineering course data from both undergraduate and graduate levels. However, this paper will focus only on the data related to undergraduate education.

The questionnaire included about twenty questions, organized into thematic sections. The first set gathered basic institutional details, such as the country and name of the respondent's university, the highest degree offered by the institution, and any additional information the respondent might be willing to share. Subsequent questions focused on the structure of geotechnical education within the undergraduate curriculum. Respondents were asked about the number of required and elective geotechnical courses, the academic year when these courses are typically offered, and the extent to which laboratory or field components are included. Particular emphasis was placed on whether soil mechanics or introductory geotechnical engineering is considered a mandatory subject.

The survey then turned to the teaching of geosynthetics, asking questions to determine whether geosynthetics are included in mandatory courses, elective courses, or not offered at all. Respondents were asked to estimate the number of contact hours dedicated to geosynthetics and to describe the instructional context in which the topic is presented—whether as part of a general discussion on construction materials, within design applications, or as a standalone subject. Open-ended prompts allowed faculty to elaborate on specific challenges or to share institutional practices regarding geosynthetics instruction.

Additional optional questions explored faculty views on the importance of teaching geosynthetics at the undergraduate level, their interest in faculty development opportunities, and their use of supplemental teaching resources, such as industry case studies or materials from professional societies. The analysis and findings from the survey data are offered in Section 5 of this paper.

4. The Case for Teaching Geosynthetics: Needs, Challenges, and Opportunities

4.1. The Need to Teach Geosynthetics

Geosynthetics have become essential in modern civil engineering. From stabilizing roadways and reinforcing walls to environmental containment and drainage, these materials are used in a wide range of infrastructure projects and have been included in national and international design standards (e.g., AASHTO, ISO, CEN). This widespread use reflects a key development in the field: What was once considered a specialized material class is now essential to everyday engineering practice. Reflecting this broad institutional integration and practical importance, the global geosynthetics market exceeded USD 16 billion in 2024 and is projected to grow to over USD 27 billion by 2033 (Precedence Research, 2024). These figures highlight an important educational need: geosynthetics are no longer peripheral to geotechnical engineering—they are now a central component of its current and future practice.

Introducing geosynthetics also helps bridge the gap between theoretical learning and real-world design practice. Unlike natural soils, geosynthetics are engineered materials with tightly controlled properties. This makes them ideal for helping students understand material selection, specification, and performance-based design. Furthermore, geosynthetics typically function within composite systems—working alongside soils or other materials—so their study naturally promotes systems thinking. When taught thoughtfully, geosynthetics become an educational link between the mechanics of materials and the complexities of infrastructure design. As Dr. J.P. Giroud, founding father of the IGS and 53rd Terzaghi Lecturer, insightfully remarked (Giroud, 2008): "What started as technology transfer from geotechnical engineering to geosynthetics engineering ended as technology transfer from geosynthetics engineering to geotechnical engineering." This reversal underscores how geosynthetics have evolved from being an applied extension to becoming a driver of innovation in geotechnical thinking.

There is also a strong case for incorporating geosynthetics from a sustainability perspective (Damians et al., 2018; Zornberg et al., 2024). These materials often allow for thinner pavement layers, more efficient earth structures, and reduced use of natural aggregates—all of which contribute to lower carbon footprints and less environmental impact. At the same time, their use generally enhances durability and extends service life, aligning with the profession's focus on resilient and sustainable infrastructure. For students, understanding these benefits helps reinforce that good engineering not only considers technical feasibility but also emphasizes long-term performance and environmental responsibility. Furthermore, including these topics in the curriculum supports key learning outcomes promoted by engineering accreditation organizations such as ABET, which requires students to understand the environmental and societal impacts of engineering solutions (ABET, 2022). It also aligns with international sustainability initiatives, especially the United Nations Sustainable Development Goals (UN, 2015), including SDG 9 on Industry, Innovation, and Infrastructure and SDG 11 on Sustainable Cities and Communities (Touze, 2021).

Importantly, this curricular modernization is both feasible and scalable. A meaningful introduction to geosynthetics can be achieved in just one class session within an introductory geotechnical engineering course. Thanks to initiatives like the International Geosynthetics Society's Educate the Educators (EtE) program, faculty now have access to modular content, instructional materials, and peer support that make integration simple. Once introduced, geosynthetics can then be revisited in more advanced or elective courses, allowing institutions to expand coverage naturally based on program goals and instructional capacity.

4.2. The Challenges of Teaching Geosynthetics

Despite the benefits mentioned earlier, incorporating geosynthetics into undergraduate civil engineering programs presents specific challenges—some related to curriculum design, others to faculty readiness, and still others to the scope and nature of the subject itself. These challenges are not impossible to overcome, but they do require targeted strategies.

One major obstacle is the curriculum limit faced by most civil engineering programs. As the technical knowledge needed by graduates keeps growing, undergraduate programs struggle to cover more material within a set number of credit hours. This forces a tough choice: adding new content often means cutting back on existing topics. In this context, newer materials like geosynthetics—despite their well-established role in engineering—are often left out of the core curriculum.

Another challenge is the limited student population that may benefit from geosynthetics instruction. In many programs, exposure to geosynthetics is limited to elective courses or isolated lectures, which means many students graduate without any formal education on the subject. To integrate geosynthetics into the core of geotechnical engineering, their inclusion should be expanded to reach all undergraduate students, even if only through a brief but strategically placed module in a required course.

The faculty readiness barrier is also significant. As already mentioned, many professors teaching geotechnical engineering today were not introduced to geosynthetics during their own education. As a result, they may lack confidence and instructional resources to teach the topic effectively. Although initiatives like the IGS's Educate the Educators program are helping to address this issue, gaps in faculty training still pose a significant obstacle to widespread adoption.

Finally, there is the didactic challenge posed by the very nature of geosynthetics. The topic of geosynthetics covers a wide variety of material types, each with different functions, properties, and applications. This complexity can seem intimidating, especially when compared to the more specific behavior of traditional soils. However, this same complexity offers valuable opportunities to connect with core geotechnical principles. When introduced thoughtfully, geosynthetics can help explain concepts like soil-structure interaction, hydraulic conductivity, and reinforcement mechanisms.

These challenges underscore the need for a teaching approach that is both strategic and inclusive. While it might not be possible to dedicate an entire course to geosynthetics in every program, even brief and well-placed exposure can ensure that all future civil engineers graduate with at least a basic understanding of these commonly used construction materials.

4.3. The Appeal of Teaching Geosynthetics

The appeal of teaching geosynthetics extends beyond their technical relevance—it also lies in their ability to inspire thoughtful, creative, and well-rounded engineering professionals. As Zornberg (2012a) points out, ingenuity is a key trait of geotechnical projects involving geosynthetics. These projects often require innovative thinking, adaptable solutions, and interdisciplinary integration. Introducing students to the ingenuity of geotechnical projects involving geosynthetics early in their education can be highly motivating, fostering a sense of discovery and highlighting the importance of innovative thinking in civil engineering.

Moreover, the breadth of geosynthetic types, functions, and applications—identified as a challenge earlier in this paper—also provides the appeal of a strong educational foundation for developing tailored solutions to engineering problems. A successful educational experience in this area does more than just transfer technical knowledge; it also helps cultivate professionals capable of critically assessing multiple design alternatives. By evaluating trade-offs involving performance, cost, constructability, and sustainability, students learn to make informed, context-aware decisions—an essential skill for modern engineering practice.

At the same time, the very nature of geosynthetic solutions promotes creativity and intellectual curiosity. Exposure to design challenges that demand novel uses of materials and interfaces encourages students to go beyond readily available design methods and to explore and solve problems. These are the very qualities—resourcefulness, adaptability, and a willingness to innovate—that define successful engineers in a changing infrastructure landscape.

Finally, for educators, integrating geosynthetics into undergraduate teaching provides an opportunity to refresh the curriculum with content that is both modern and engaging. The field's energy and practical importance enable instructors to involve students through design-focused projects, case studies, and applied research, bringing engineering education closer to real-world challenges and opportunities.

4.4. Using Geosynthetics to Strengthen Geotechnical Understanding

Integrating geosynthetics into undergraduate courses does more than introduce a new type of geomaterials; it provides an effective way to improve and deepen students' understanding of fundamental geotechnical concepts. A primary feature of geosynthetics with strong teaching advantages is that their functions (e.g., reinforcement, filtration, barrier) are clearly defined, offering a simple way to illustrate key geotechnical ideas.

For example, geosynthetics offer an excellent opportunity to review and apply concepts related to drainage and flow through porous media, especially when examining the filtration and drainage functions of geotextiles and geonets. Likewise, discussions on reinforcement mechanisms provide a tangible way to revisit the shear strength of soils and the effects of confining stress. In topics like slope stability and retaining structures, incorporating geosynthetics allows students to explore failure modes, load transfer mechanisms, and interface behavior with clarity and a focus on design.

Moreover, the modular and application-oriented nature of geosynthetics education promotes interdisciplinary integration. Concepts from soil mechanics, hydraulics, and environmental engineering are combined in analyzing geosynthetic barrier systems and reinforced soil structures. As a result, students gain not only exposure to advanced applications but also a deeper understanding of the fundamental principles behind them.

In the words of Prof. Marina Pantazidou, Chair of TC306 (ISSMGE Technical Committee on Geotechnical Education), “Understanding how geosynthetics work together with soils helps me understand better how soils work" (Pantazidou, 2023). Section 7 of this paper will present and discuss educational strategies that illustrate how teaching geosynthetics can enhance the understanding of key geotechnical concepts.

5. Findings from the International Survey on Undergraduate Geotechnical Engineering Education

5.1. Characteristics of Participating Institutions

As previously summarized in Table 2, the survey respondents represented a diverse and well-distributed cross-section of academic institutions within the nine selected countries. The level of engagement was high across regions, with particularly strong participation from countries such as Argentina, Brazil, Canada, Greece, and the USA, all of them with a response rate of about 80% or higher.

The distribution of responses across these countries is shown in Figure 1, which provides a visual summary of institutional participation grouped by program structure (i.e., 4- vs 5-year programs). Among the countries where the undergraduate civil engineering degree is typically completed in four years—namely the United States, Turkey, India, and Canada—the highest number of responses came from the United States (109 responses), representing about 84% of American civil engineering programs. In the group of countries with five-year undergraduate programs—Argentina, Brazil, Colombia, Germany, and Greece—the most responses were from Brazil (44 responses), accounting for about 79% of the Brazilian programs. Although responses from Greece (7 responses) are relatively small, they represent 100% of the civil engineering programs identified in that country.

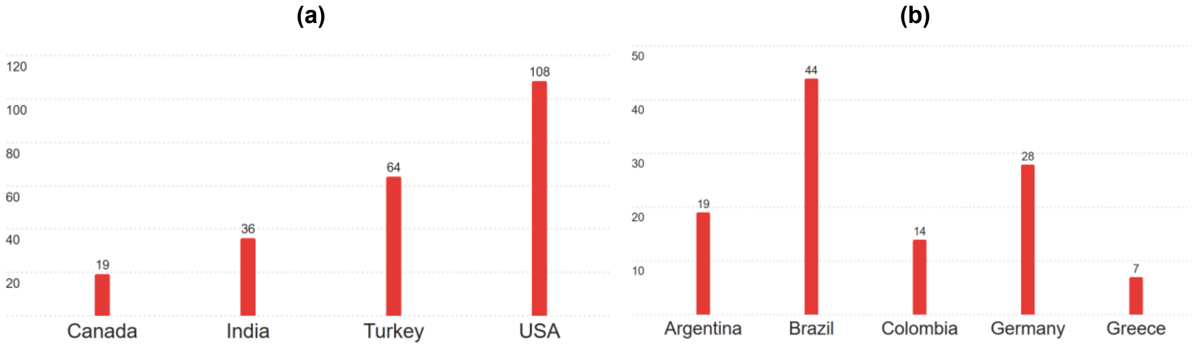

Figure 1. Total number of institutions participating in the educational survey grouped by country: (a) 4-Year Programs; (b) 5-Year Programs

Participating institutions included a mix of large public universities, technical institutes, and private engineering schools, showcasing a variety of curricular structures and educational missions. The language of instruction differed by country, including Spanish, Portuguese, English, German, Greek, and Turkish, highlighting the international scope of civil engineering education in this study. In several instances, programs were offered in more than one language or featured tracks with international accreditation.

Although the main focus of this study is on undergraduate education, responses indicating the highest degree awarded by participating institutions provide useful context for interpreting the survey trends. The vast majority of the participating institutions (86%) offer a Doctorate (Ph.D.) in programs related to geotechnical engineering, while an additional 8% report a Master’s degree as the highest credential. Only a small percentage (4%) are programs that only offer undergraduate degrees, and 2% of the respondents indicated other structures. Figure 2 displays the highest degree awarded by participating institutions per country for 4- and 5-year degree programs. The common offering of Ph.D. degrees across both 4-year and 5-year systems indicates that the surveyed institutions generally have a strong academic foundation. The data in Figure 2 thus provide an important basis for understanding future trends in curricular content. Specifically, later comparisons of the number of undergraduate lectures that include geosynthetics (discussed in subsequent sections) are not expected to be affected by differences in institutional depth or degree capacity.

Overall, the high response rates and broad representation of program types, institutional missions, and national educational standards ensure that the survey's findings can be interpreted within a meaningful global context.

(a) **(b)**

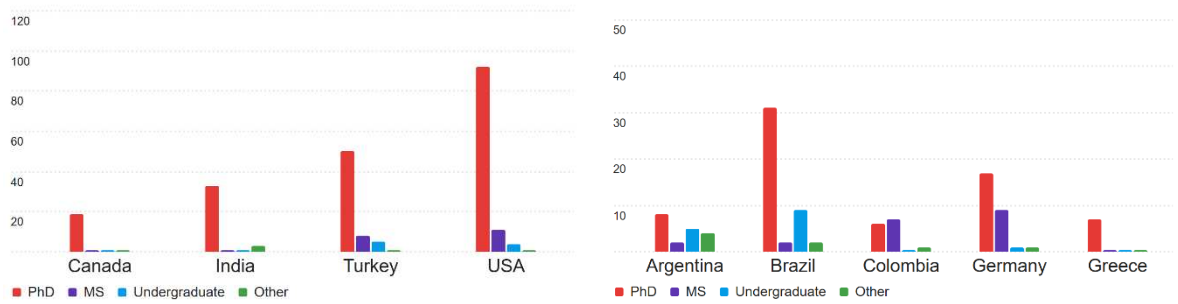

Figure 2. Total number of institutions participating in the education survey, categorized by the highest degree awarded: (a) 4-Year Programs; (b) 5-Year Programs

5.2. The State of Geotechnical Education in Undergraduate Civil Engineering Programs

The survey results provide detailed insight into how many mandatory geotechnical engineering courses are included in undergraduate civil engineering programs across the nine participating countries. These data, presented in **Figure 3**, are critical for understanding whether students are guaranteed exposure to geotechnical content—and, by extension, to geotechnical subfields such as geosynthetics—regardless of institutional or national context. Figure 3a illustrates the distribution of responses from countries with four-year undergraduate programs (United States, Canada, India, and Turkey), while Figure 3b presents the same information for countries with five-year programs (Argentina, Brazil, Colombia, Germany, and Greece).

(a) **(b)**

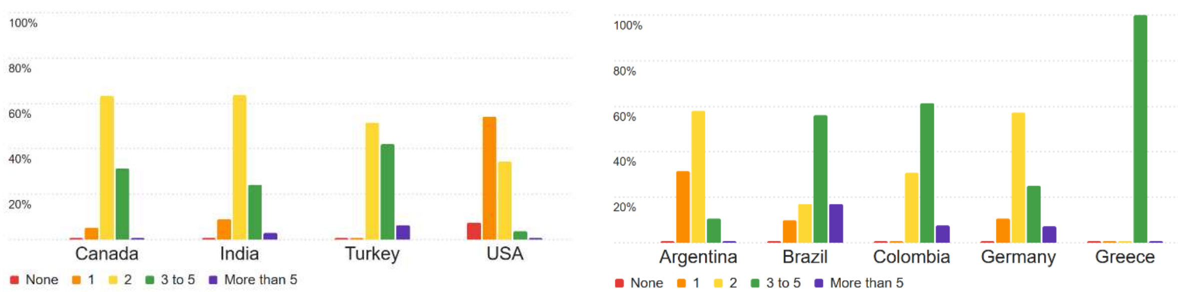

Figure 3. Number of mandatory geotechnical engineering courses: (a) 4-Year Programs; (b) 5-Year Programs

In the 4-year group, Turkey demonstrated a notably strong inclusion of geotechnical engineering in the civil engineering curriculum, with 100% of institutions offering at least two mandatory geotechnical engineering courses, and 48% offering three or more. Canada also shows a strong presence, with 95% of programs requiring at least two mandatory geotechnical engineering courses, and 32% offering three or more. India exhibits similar figures to Canada, with 91% of programs requiring at least two mandatory geotechnical engineering courses, and 27% offering three or more. However, the United States displays a concerning trend, with 7% of participating institutions indicating no mandatory geotechnical engineering courses in their civil engineering programs. This suggests that students from these programs may graduate as civil engineers without having taken a single geotechnical engineering course. Additionally, in the US, only 39% of programs require at least two mandatory geotechnical courses, and just 4% offer three or more. While elective geotechnical engineering courses are generally available in the US programs, the limited number of mandatory courses raises questions about whether students in these programs receive enough exposure to core geotechnical concepts.

In contrast to the 4-year programs, the 5-year programs (Figure 3b) showed a more consistent commitment to geotechnical education. No institution in this group reported the absence of a required geotechnical course. Greece, for example, reported that 100% of its surveyed institutions offer three to five required geotechnical courses, possibly highlighting a particularly strong national dedication to the field. Colombia also demonstrated a significant inclusion of geotechnical engineering in the civil engineering curriculum, with all institutions offering at least two mandatory geotechnical engineering courses, and 69% offering three or more. Brazil has similar figures to Colombia, with 90% of programs requiring at least two mandatory geotechnical engineering courses, and 73% offering three or more. Germany showed a broader distribution: 89% of the programs offer at least two mandatory geotechnical engineering courses, with 32% offering three or more. The programs in Argentina show a comparatively smaller presence of mandatory geotechnical engineering courses than those in other countries with 5-year programs. Specifically, 68% of the programs offer at least two mandatory geotechnical engineering courses, with only 10% offering three or more.

The comparison between the two groups of countries reveals a predictable yet clear pattern: programs with longer durations tend to include more mandatory geotechnical courses. The only reported instances of programs lacking any such mandatory courses occurred among the 4-year programs (all of which are in the U.S.). While strong geotechnical education is still evident in most 4-year systems, it is within the 5-year structures that the most consistent and intensive coverage of geotechnical content can be observed among required undergraduate coursework.

The gap in geotechnical coverage between 4- and 5-year programs may warrant a call to action within the geotechnical community to reduce adverse educational impacts in geotechnical engineering. This is especially important given a significant global trend: the shortening of civil engineering degree programs. For example, Argentina historically offered six-year civil engineering degrees, which have now been shortened to five years. Colombia, currently offering five-year programs, is considering moving to a four-year model, aligning with other international trends. This shift toward shorter degrees is primarily driven by efforts to harmonize curricula, enhance international mobility, and increase the cost-effectiveness of engineering education (Bonilla-Petriciolet et al., 2021; Nguyen & Habók, 2021).

While this shift may be irreversible, its effects must be approached carefully. When undergraduate programs are squeezed, key subjects like geotechnical engineering risk being marginalized, not because they are unimportant, but due to increased competition for limited curriculum space. It is therefore crucial to stress that certain topics must remain core to all civil engineering programs, regardless of length. Geotechnical engineering—and within this field, geosynthetics—are examples of critical subject areas that should not be postponed to graduate-level education.

The argument that students can simply specialize later through graduate studies (for example, a Master's in Geotechnical Engineering) does not address the core issue. Not all civil engineering students will pursue graduate degrees, and even among those who do, specialization typically happens after their educational paths and professional identities have already begun to form. If foundational exposure to geotechnical topics is missing at the undergraduate level, students might be unprepared to understand or engage with these subjects later. Additionally, topics like geosynthetics are increasingly important across various civil engineering fields—including pavements, environmental containment, and retaining structures—making them relevant to all practicing civil engineers, not just those who decide to specialize.

To complement the analysis of mandatory courses, Figure 4 shows the number of elective geotechnical engineering courses offered by participating institutions. Figure 4a presents the results for countries with four-year programs, while Figure 4b displays the results for countries with five-year programs. In the 4-year group, most (but not all) institutions report offering at least one elective geotechnical course. For instance, in the United States, 8% of programs offer none, 69% offer two or more elective geotechnical courses, and 44% offer three or more. The distribution of elective geotechnical courses is fairly similar among the four countries with 5-year programs evaluated in this study. For example, about half of the programs in each country offer at least three elective geotechnical courses.

The 5-year group, however, shows a more diverse picture. Generally, and perhaps because they offered a larger number of mandatory geotechnical courses compared to the 4-year group, the number of electives in the 5-year group is relatively smaller than in the 4-year group. For example, survey data indicates that 68% of civil engineering programs in Argentina do not offer any elective geotechnical courses. Additionally, 32% of programs in Germany offer no elective geotechnical courses, and 36% of the remaining programs in this country offer only one such elective course. On the surface, these findings might suggest weaker support for geotechnical depth in five-year programs. However, this interpretation would be inaccurate without considering the number of mandatory courses discussed earlier. Conversely, Brazil, Colombia, and Greece provide a relatively strong number of elective geotechnical courses, with 55%, 62%, and 72% of programs in these countries offering at least three geotechnical technical electives. Notably, 43% of the programs in Greece offer more than five elective geotechnical courses.

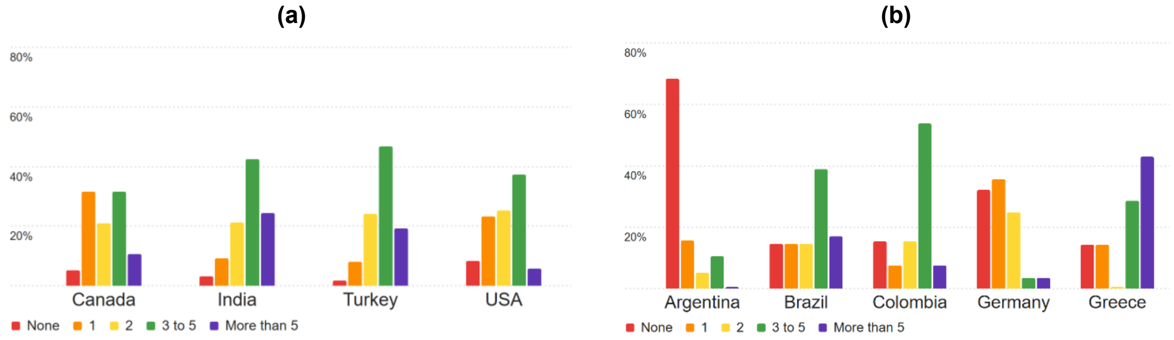

Figure 4. Number of elective geotechnical engineering courses: (a) 4-Year Programs; (b) 5-Year Programs

Indeed, interpreting elective offerings requires context. The survey asked institutions to report the number of elective courses separately from required ones. As a result, the analysis does not directly show whether electives are meant to supplement, complement, or replace core instruction. The trend in the number of elective courses in 4-year programs appears to balance out the number of mandatory courses. For example, in the U.S., the results from Figure 3a indicate that a relatively high percentage (61%) of programs offer one or no mandatory geotechnical engineering courses. This seems to be balanced by a healthy number of electives, with 68% of programs offering at least two elective courses in geotechnical engineering. Conversely, the trend in the number of elective courses in 5-year programs seems inconsistent with the number of mandatory courses. For instance, in Argentina, a high percentage of programs (90%) offer a small number of mandatory courses (two or fewer), yet a large proportion (68%) also offer no elective geotechnical courses. This possibly highlights a lack of opportunities for students to gain foundational geotechnical knowledge. The opposite occurs in Greece, where all programs (100%) include three to five mandatory geotechnical courses, and 43% of programs offer more than five elective courses, indicating particularly strong opportunities for geotechnical engineering education.

Therefore, the most meaningful way to interpret Figure 4 is not by viewing elective courses as standalone indicators of strength or weakness, but by analyzing them alongside mandatory course offerings. Elective geotechnical courses add depth and flexibility to the curriculum, allowing interested students to pursue further specialization. However, they cannot compensate for the lack of fundamental instruction in the required courses. In an era of increasingly compressed undergraduate programs, safeguarding both required and elective opportunities for geotechnical education becomes critical, not only for future specialists but for all civil engineers involved in some form of civil infrastructure design.

5.3. The State of Geosynthetics Education in Geotechnical Courses

The extent to which geosynthetics are incorporated into mandatory undergraduate civil engineering courses varies significantly among the surveyed countries. Figure 5 presents the number of hour-long class sessions in which geosynthetics content is addressed within required coursework. Figure 5a shows the results for countries with 4-year programs (United States, Canada, India, and Turkey), while Figure 5b shows the corresponding data for countries with 5-year programs (Argentina, Brazil, Colombia, Germany, and Greece).

In the 4-year group (Figure 5a), the United States stands out as the country with the lowest level of coverage. A full 71% of institutions report that geosynthetics are not covered at all in any mandatory undergraduate course. Among the remaining programs in the U.S., 21% report 1 hour of coverage and 7% report 2 hours. This suggests that when geosynthetics are included, they are typically introduced in a very limited way—often as part of a single lecture. The coverage of geosynthetics in mandatory courses in the rest of the 4-year programs (Canada, India, and Turkey) is not significantly better than in the U.S. and is quite consistent. Specifically, 58% of institutions in each of these three countries report that geosynthetics are not covered in any mandatory undergraduate civil engineering course.

The 5-year group (Figure 5b) displays more diverse patterns. Brazil clearly leads in geosynthetics coverage in mandatory courses among all surveyed countries. While 20% of Brazilian programs report no mandatory coverage, the rest show a broad range: 29% report 1 hour, 17% 2 hours, 24% 3 to 5 hours, and notably, 10% of programs (4 institutions) report more than 5 hours of geosynthetics instruction in required geotechnical engineering courses. This reflects a strong and growing recognition of the importance of geosynthetics within Brazil's undergraduate civil engineering education. Argentina also shows meaningful inclusion, with 42% of programs reporting 2 hours, and another 26% reporting 3 to 5 hours. In Colombia, 46% of programs report 1 hour, but about one-third of institutions (31%) indicate that geosynthetics are not covered in any required course. Germany and Greece, despite offering relatively healthy offerings in terms of the number of mandatory undergraduate geotechnical engineering courses, exhibit the lowest inclusion among the 5-year countries: 64% of German institutions and 86% of Greek institutions report no coverage of geosynthetics in required geotechnical coursework.

(a) (b)

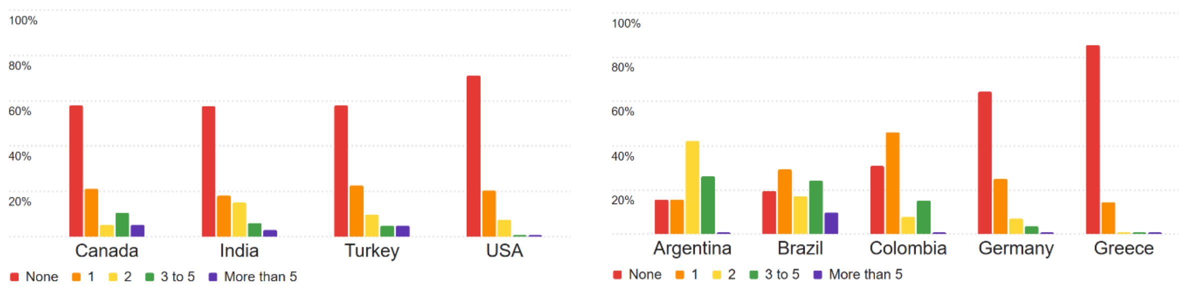

Figure 5. Number of hour-long classes that include geosynthetics in mandatory courses: (a) 4-Year Programs; (b) 5-Year Programs

The comparison between Figures 5a and 5b reveals several important insights. First, the length of the program does not seem to be a dependable predictor of whether geosynthetics will be included in the required geotechnical courses. While it might be expected that 5-year programs would have more room to incorporate specialized content, this is not consistently the case. In fact, some of the lowest inclusion rates (e.g., Germany and Greece) are observed in countries with a strong number of mandatory courses. Conversely, several 4-year countries (e.g., Canada, India, and Turkey), despite their limited curricular space, show that 42% of their programs provide at least one hour of geosynthetics instruction in their required geotechnical engineering courses.

It seems that the key difference is not in program length but in curricular priorities and institutional emphasis. Among all countries, Brazil stands out as the most comprehensive in incorporating geosynthetics into required undergraduate courses, both in the number of programs that include the topic and in the depth of instruction provided. This demonstrates not only a curricular focus on geotechnical issues but also an obvious institutional recognition of the practical importance of geosynthetics in civil engineering applications.

These findings strengthen an important argument for geosynthetics education: it should not be considered an advanced or optional subject to be reserved for elective courses or postgraduate specialization. Instead, geosynthetics are a crucial part of modern geotechnical engineering, relevant to fundamental topics like slope stability, retaining structures, pavement design, and environmental containment. The lack of geosynthetics in required undergraduate courses means many civil engineers will graduate without even a basic knowledge of materials and systems they are likely to face in practice.

The data from Figures 5.5a and 5.5b, therefore, highlight an important challenge: ensuring all students, regardless of institutional context or program length, receive at least minimal, meaningful exposure to geosynthetics as part of their required civil engineering education. This goal is essential not only for promoting technical competence but also for making sure that future engineers are prepared to make informed decisions about a class of materials that continues to grow in relevance and application.

Complementing the analysis of required coursework, Figure 6 shows the number of hour-long sessions dedicated to geosynthetics within elective undergraduate courses. While elective offerings allow for deeper exploration of specialized content, they do not guarantee universal exposure. In the 4-year group (Figure 6a), Canada and U.S. stand out with a sizable number of programs that offer no geosynthetics coverage among the elective geotechnical courses (53% and 40%, respectively), yet a nonnegligible number of programs offer at least 6 hours of geosynthetics coverage among the elective geotechnical courses (27% and 12%, respectively). India stands out among the countries in this group by having possibly the largest covering of geosynthetics in elective courses (at least 60% of the institutions offer 3 or more hours of geosynthetics coverage in these courses.

In the 5-year group (Figure 6b), the number of institutions that do not offer any geosynthetics coverage in their elective courses is staggering: 84% in Argentina, 79% in Germany, 43% in Greece, 32% in Brazil, and 31% in Colombia. On the more positive side, Greece and Brazil have the highest percentages

(43% and 37%, respectively) of institutions that offer at least 3 hours of geosynthetics in their elective geotechnical courses. These data confirm that elective courses can enhance the curriculum but cannot replace the guaranteed instruction provided through required coursework. Ensuring that geosynthetics is incorporated into the core curriculum remains essential to prepare all students—not just those pursuing specialized tracks—for the demands of modern geotechnical practice.

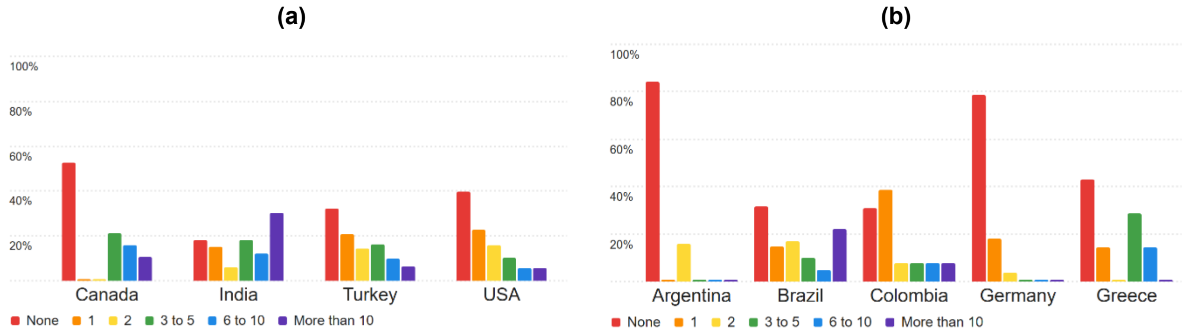

Figure 6. Number of hour-long classes that include geosynthetics in elective courses: (a) 4-Year Programs: (a) 4-Year Programs; (b) 5-Year Programs

6. Institutional Tools for Integrating Geosynthetics in the Classroom

6.1. The International Geosynthetics Society (IGS)

The International Geosynthetics Society (IGS) has served as the main global organization dedicated to advancing geosynthetics in engineering, education, and research. Founded in 1983 in Paris as the International Geotextile Society, the IGS expanded its scope to include all geosynthetic materials, leading to its current name adopted in 1994. This change reflected the diversification of geosynthetics themselves—from geotextiles to a broad range of engineered polymer products, each providing unique functions in geotechnical, hydraulic, and environmental applications.

IGS has expanded into a global organization with over 3,000 members through a network of national and regional chapters. Its governance structure—led by a democratically elected council—ensures international representation and stability. The society offers a platform for dialogue and knowledge sharing among researchers, practitioners, educators, and industry stakeholders across all continents. A key role of IGS is disseminating knowledge through activities like sponsoring two leading peer-reviewed journals—Geotextiles & Geomembranes and Geosynthetics International—and organizing the quadrennial International Conference on Geosynthetics, regional conferences, and technical workshops. Its support for technical committees focused on specialized areas such as soil reinforcement, barrier systems, and sustainability is equally vital. These activities not only produce state-of-the-art documents but also promote international technical collaboration.

Education has been a core mission of the IGS for a long time. Starting in the 2000s, the Society introduced student memberships, encouraged young professionals to get involved through awards, and conducted outreach to promote geosynthetics education. Additionally, the IGS has worked with standards organizations like ASTM/D35 and ISO/TC 221 to develop terminology, testing procedures, and design guidelines that support consistent global adoption.

Together, these activities reinforce IGS's core purpose: to provide understanding and promote the appropriate use of geosynthetic technology worldwide. This institutional foundation—combining scholarly publishing, global conferences, technical guidance, and student outreach—has enabled the launch and success of targeted educational programs. Chief among these is the Educate-the-Educators (EtE) initiative, which is discussed in the next section.

6.2. The IGS' Educate-the-Educators (EtE) Program

To address potential challenges of teaching geosynthetics in undergraduate civil engineering programs, the International Geosynthetics Society (IGS) launched the Educate-the-Educators (EtE) initiative in 2013. Designed to empower university faculty—especially those unfamiliar with geosynthetics—this program provides both technical content and pedagogical strategies needed to incorporate geosynthetics instruction into existing engineering curricula (Zornberg et al., 2020; Gardoni et al., 2024).

The inaugural EtE event was held in Argentina, and the model has since been successfully replicated across many countries and continents.

The EtE initiative was created to fill a perceived educational gap: most undergraduate civil engineering students graduate with minimal or no exposure to geosynthetics, despite their widespread application in infrastructure design and construction. This problem is compounded by a generational knowledge gap—many faculty currently teaching geotechnical courses were never trained themselves in geosynthetics (Zornberg et al., 2020). The EtE program directly tackles this dual challenge by offering instructors modular, ready-to-use content that can be tailored to different institutional contexts.

Each EtE event usually includes an intensive, multi-day workshop that combines theoretical lessons, hands-on demonstrations, and curricular planning. Participants receive a variety of resources—including slide decks, design examples, case histories, and physical samples of geosynthetics—to help incorporate the material into the classroom with minimal preparation. A fundamental idea of the initiative is that even just one hour of geosynthetics instruction, if given to all civil engineering undergraduates, can significantly improve their professional readiness (Zornberg et al., 2020). Events also provide opportunities for more advanced implementations, such as creating elective courses and graduate-level modules.

Follow-up assessments, especially those in Brazil, demonstrated the program's effectiveness. As of June 2025, 30 EtE events had been held in 21 countries, reaching over 800 university professors. Survey data from these events show that between 60% and 90% of attendees incorporated geosynthetics into their courses, and 10% to 17% went further to develop standalone instructional modules (Gardoni et al., 2024). Instructors have also expanded the program’s reach by organizing local seminars, delivering public lectures, or advising government agencies on curriculum development.

EtE workshops are funded by IGS and local chapters. They cover instructor costs, accommodation, and materials, with participants only covering their travel. The workshops involve local geosynthetics industry partners to facilitate practical product identification sessions and real-world case discussions. Recognizing the need for ongoing support, the IGS Foundation, established in 2021, has coordinated complementary funding.

The EtE initiative serves as a model for how professional societies can drive educational change. By connecting technical content with scalable implementation methods, the IGS has developed a program that not only fills a specific curriculum gap but also builds a global community of educators dedicated to modernizing geotechnical teaching.

7. Strategies for Teaching Geosynthetics in Undergraduate Education

7.1. Provide Early Exposure to Geosynthetics as a Core Geotechnical Material

One key strategy promoted in this paper is to introduce students to geosynthetics early in their education, typically during the mandatory introductory course for all civil engineering undergraduates. Incorporating geosynthetics into this course, which often emphasizes soils as a primary material, helps students see these materials not as optional or secondary, but as core geomaterials in geotechnical engineering. This first exposure provides a conceptual foundation for understanding the mechanical and hydraulic properties of geosynthetics alongside soils, promoting early comparisons and a more integrated understanding.

The first geotechnical engineering course in most civil engineering programs functions as a “materials” course, introducing students to the engineering behavior of an essential civil engineering material: soils. The proposal here is not to shift the course’s purpose toward geotechnical applications or design but to slightly broaden its scope to include synthetic geomaterials as part of the same foundational framework. Geosynthetics, alongside soils, should be presented as essential construction materials within the geotechnical engineer’s toolkit. As highlighted by the findings from the survey conducted in this study (see Section 5.3), this introductory course may be the only chance for all civil engineering students—including those who will not pursue geotechnical electives—to be exposed to geosynthetics. In many academic programs, particularly in the United States, this single course is the only required geotechnical instruction, making it crucial to maximize that opportunity.

Currently, when geosynthetics are introduced at the undergraduate level, it typically occurs in geotechnical “applications” or within design-focused electives. This approach introduces geosynthetics late in the curriculum—if at all—and misses the chance to connect their properties and functions with fundamental soil mechanics instruction. Conversely, introducing them early enables teaching geosynthetics alongside core geotechnical concepts. For example, students can draw parallels between the tensile behavior of geogrids and the frictional resistance of soils or between the filtration function of geotextiles and that of granular materials. Survey results in Section 5.3 further support that, when included, geosynthetics are included in the curriculum, this often occurs in elective courses not taken by all students, contributing to unevent exposure even within the same academic institution.

Introducing geosynthetics early also helps clarify the concept of "functions" in geotechnical materials, an idea central to performance-based design that students will encounter later in the curriculum. While students near the end of their introductory geotechnical engineering course have been exposed to a wide range of soil properties—from physical properties like specific gravity, to compositional ones such as plasticity index, to hydraulic properties like saturated hydraulic conductivity, and to mechanical properties like compression index and effective friction angle—these are rarely presented as ways to meet specific geotechnical functions. Unlike soils, geosynthetic properties are introduced through their engineered functions: separation, reinforcement, stiffening, filtration, barrier, drainage, and protection. Recognizing these functions (for both natural and synthetic geomaterials) gives students a framework for choosing material properties based on the intended use. Ultimately, this view can help students better understand the functional role of natural geomaterials (i.e., soils themselves) and serve as a pedagogical entry point for gaining deeper insight into the role of both synthetic and natural geomaterials in the built environment.

Importantly, incorporating geosynthetics into the introductory geotechnical course does not require extensive coverage. Even a single hour-long lecture, delivered to all undergraduate students, can establish foundational awareness. Though modest in duration, this exposure can have a far-reaching impact: ensuring that every graduating civil engineer—regardless of future specialization—leaves with basic knowledge of a class of materials central to modern infrastructure practice. Sensitive to the curricular challenges in civil engineering programs (see discussion in Section 4.2), this recommendation considers key constraints, such as limited instructional time, rigid curricula, and the competing demands of accreditation standards. To assist with implementation, the International Geosynthetics Society (IGS) offers a fully developed one-hour lecture on geosynthetics, complete with slides and a recorded presentation, freely available through its website (Zornberg, 2021). For courses that include laboratory sessions, simple experiential activities—such as tactile identification of different geosynthetic products—can also be integrated, as outlined on the IGS experiential learning webpage. Even brief, well-placed exposure to foundational concepts can lead to long-term retention and understanding, especially when aligned with core learning principles that emphasize early activation of prior knowledge and relevance (Ambrose, 2020).

Survey findings (Section 5.3) emphasize the importance of early inclusion: geosynthetics are often left out of required coursework, especially in four-year programs. Exposure is usually limited to electives, which many students never choose. This fragmented approach creates widespread gaps in preparedness. Introducing geosynthetics in the initial geotechnical course addresses this issue by presenting them not as secondary topics, but as vital geotechnical materials that all civil engineers need to understand.

7.2. Emphasize the Role of Geomaterials as Essential "Construction" Materials

By the end of the introductory geotechnical engineering course, students usually realize that soils, unlike materials such as concrete or steel, are not manufactured to uniform standards. Instead, soils are natural geomaterials with high variability and site-specific properties. This variability requires careful experimental characterization, as each soil is essentially unique. Consequently, much of geotechnical education focuses on learning how to classify, test, and interpret soil behavior, highlighting the importance of tailored assessments for both design and construction.

However, the characterization of geomaterials goes beyond simply analyzing the subsurface conditions that support structures, such as a building's deep foundation system. In addition to their structural support role, soils and other geomaterials are frequently used as construction materials in civil engineering projects, like building earth dams, embankments, and waste containment systems. Recognizing this dual purpose is essential. The idea of using soil as a construction material may have been touched upon in introductory courses, typically in the context of compaction. However, students may not fully appreciate how frequently and fundamentally geomaterials are selected, processed, and placed for construction purposes. This includes sourcing from borrow pits, assessing suitability, and sometimes modifying or blending materials based on availability, transportation distance, and performance needs.

The discussion of geosynthetic functions offers a teaching entry point to highlight the role of geomaterials in construction. When students learn how geosynthetics are chosen for specific functions, they start to see similarities with how soils must be selected and placed to meet the same performance goals. Although it may seem obvious that geomaterials like gravel, clay, sand, or geotextiles are not interchangeable, the idea of "functions" helps clarify why careful material specifications are needed to ensure that differences among geomaterials are expressed through relevant properties, leading to the construction of a geotechnical system that performs as intended.

A useful example comes from the function of separation. This function, often fulfilled by geotextiles, involves preventing the mixing of dissimilar soils, such as a clean granular base layer overlying a soft clay subgrade in road construction. Intermixing may significantly compromise the performance of the granular base by lowering its shear strength, drainage ability, and long-term stability. Understanding geosynthetics highlights the importance of preventing such mixing, a concern relevant to many geotechnical systems. However, this idea—that different soils fulfill distinct functions and should often be kept apart—is seldom emphasized in introductory courses, despite its crucial role in real-world geotechnical construction.

Another instructive example is the barrier function, especially in the context of hydraulic containment systems used in landfills, tailings dams, and water retention structures. Historically, compacted clay has been the natural material of choice for creating low-hydraulic-conductivity barriers. However, the advent of geosynthetics such as geomembranes and geosynthetic clay liners (GCLs) has broadened the range of materials available for this purpose. In fact, the most effective barrier systems are composite barriers—systems that combine a geomembrane with a compacted clay layer. The intimate contact between these materials minimizes leakage and provides redundancy in containment, significantly improving their long-term performance. The synergy between natural and synthetic geomaterials is well established in the literature; Giroud and Bonaparte (1989) identified composite liners as best practice for minimizing leakage in containment applications.

Recognizing geomaterials as functional construction materials—whether natural or synthetic—gives students a more accurate and practice-oriented view of geotechnical engineering. It highlights that material selection is not just about classification or compliance, but about purpose, performance, and compatibility. Introducing this mindset early in the curriculum helps students gain a deeper understanding of how geotechnical systems are assembled, why material interfaces matter, and how design choices are influenced by both natural variability and engineered solutions. In this context, geosynthetics serve not only as high-performance materials but also as educational tools that explain the construction role of all geomaterials in civil infrastructure.

7.3. Draw Parallels between Geosynthetics and Soil Mechanics Principles

Core concepts in teaching synthetic geomaterials (geosynthetics) closely resemble those of earthen geomaterials such as soils and rocks. Many mechanical and hydraulic principles used to analyze and design soils are equally applicable to geosynthetics. This conceptual similarity offers valuable teaching opportunities. Educational modules on material properties can emphasize clear similarities between the behaviors of geosynthetics and core principles of soil mechanics, improving student understanding through side-by-side comparison.

The functional use of both natural and synthetic materials in applications related to drainage, filtration, and stiffening can provide a natural basis for reinforcing traditional geotechnical engineering concepts. These functions can be explained using terms familiar to students from previous lectures. For instance, designing drainage systems with soils and geosynthetics draws directly on the concept of hydraulic conductivity; filtration relates to cross-plane flow; and stiffening involves increasing confinement within the soil mass, directly influencing shear strength and modulus. These parallels not only improve technical understanding but also encourage a systems-level perspective on how different geomaterials interact in the built environment, a pedagogical approach grounded by evidence showing that connecting new material to students' prior knowledge significantly enhances learning outcomes (Ambrose, 2020).

A particularly effective teaching opportunity arises from the drainage function of geosynthetics, which can be used to revisit in-plane flow governed by Darcy's Law. Traditionally, this principle is introduced by analyzing flow through soil layers. However, the same governing relationship applies to geosynthetics, with minor modifications in terminology. Figure 7 shows the actual slide used to introduce the concept of in-plane drainage in an introductory geotechnical engineering class. For flow through a soil layer of thickness t, Darcy's Law is expressed as:

$$Q = k_p \cdot \frac{\Delta h}{\Delta l} \cdot w \cdot t \qquad (1)$$

where Q is the total flow rate, k_p is the in-plane hydraulic conductivity of the medium, Δh/Δl is the hydraulic gradient, *w* is the width of the drainage path, and t is the thickness of the layer. As shown in the figure, this could be rewritten as:

$$Q = \theta \cdot i \cdot w \quad (2)$$

where θ is the transmissivity of the geosynthetic and i is the hydraulic gradient. Transmissivity itself is defined as:

$$\theta = k_p \cdot t \quad (3)$$

This parallel structure allows students to see how traditional fluid flow concepts carry over to geosynthetic materials. By presenting these formulations together, instructors can reinforce the underlying physics of seepage while simultaneously introducing terminology specific to geosynthetics.

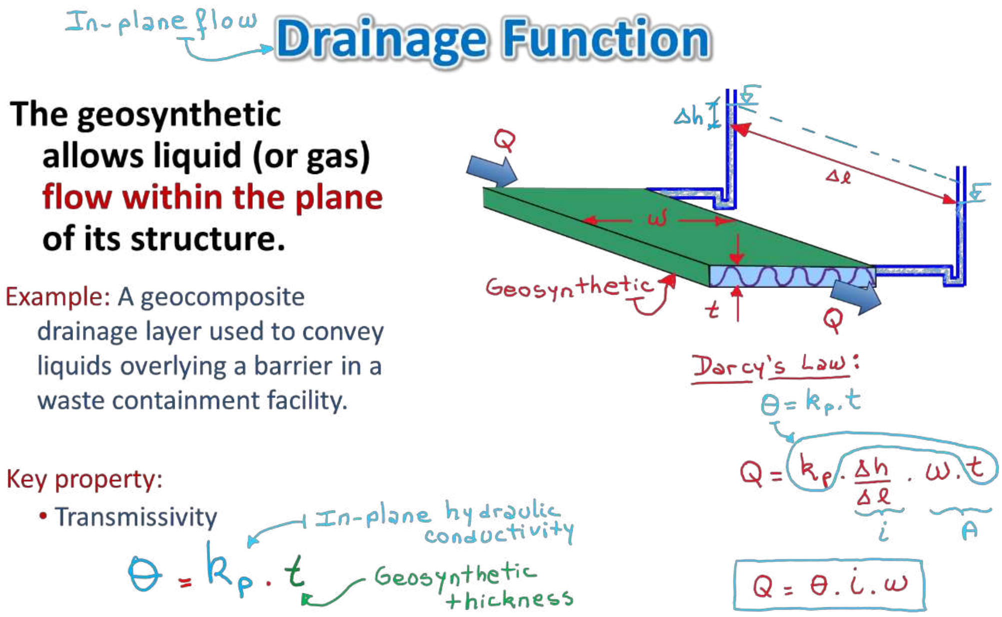

Figure 7. Slide illustrating the drainage function in a geosynthetics lecture, focusing on complementing earlier content in a typical introductory geotechnical engineering course

A similar opportunity arises when discussing the filtration function of geosynthetics, which involves cross-plane flow and leads to the definition of permittivity. Figure 8 shows the slide used for this concept in an introductory geotechnical engineering class. Again, Darcy's Law applies, but for flow normal to a geosynthetic layer, we'll have:

$$Q = k_n \cdot \frac{\Delta h}{t} \cdot A \quad (4)$$

where k_n is the cross-plane hydraulic conductivity of the material, Δh is the head difference, t is the thickness, and A is the cross-sectional area normal to flow. For ease of characterization in thin manufactured products, the concept of permittivity (ψ) is introduced:

$$\psi = k_n / t \quad (5)$$

This leads to the commonly used flow expression for geosynthetics:

$$Q = \psi \cdot \Delta h \cdot A \quad (6)$$

Permittivity is a standard property in geosynthetics testing, commonly reported in product datasheets. Teaching this relationship allows students to strengthen their grasp of Darcy's Law while introducing the hydraulic parameters used in geosynthetics characterization. The consistent mathematical framework helps unify traditional flow concepts with relevant characterization of geosynthetics properties.

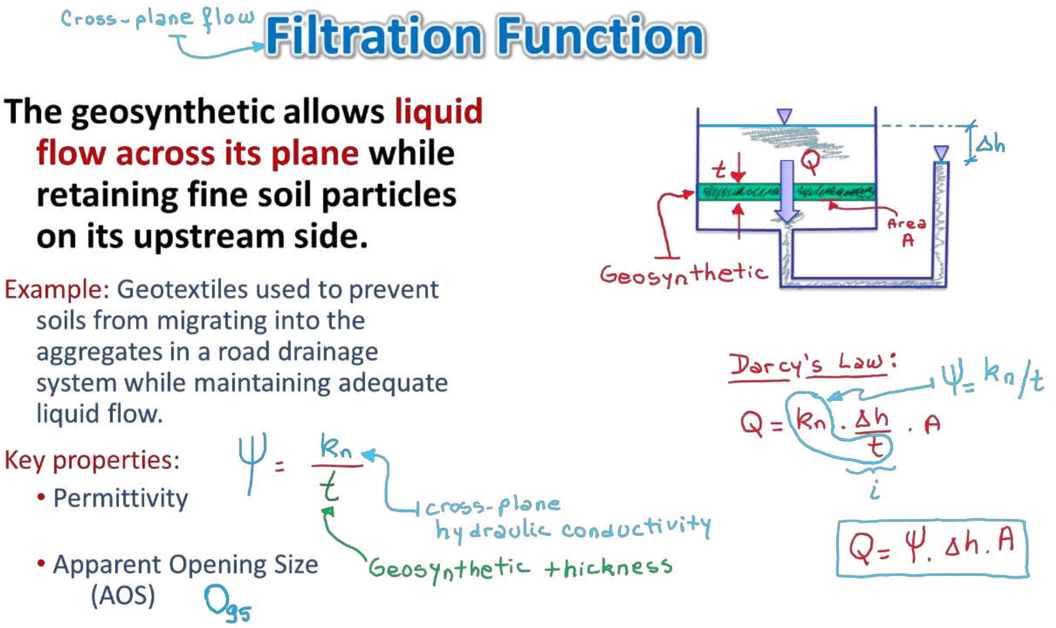

Figure 8. Slide illustrating the filtration function in a geosynthetics lecture, focusing on complementing earlier content in a typical introductory geotechnical engineering course

A third instructive example emerges from the stiffening function of geosynthetics. This concept is not directly addressed in standard geotechnical curricula, yet it highlights an important mechanical principle: the confinement sensitivity of granular soils. Specifically, discussing the stiffening function allows highlighting how granular soils exhibit excellent mechanical behavior—high shear strength and modulus—but only when confined. Using geosynthetics, especially in applications like geogrid-stabilized pavements or geocell-reinforced bases, provides lateral restraint that improves confinement. This leads to increased modulus, improved load distribution, and reduced permanent deflections.

Introducing the stiffening function of geosynthetics helps students visualize and quantify how confinement affects soil behavior. It also links soil mechanics concepts like shear strength and modulus to system-level thinking about load transfer. This integrated view aids students in understanding how engineered solutions, such as geosynthetic stabilization, are rooted in fundamental soil behavior and can be optimized through proper interaction between materials.

In summary, teaching geosynthetics offers a unique opportunity to reinforce, expand, and unify traditional soil mechanics principles within a practical context. Whether through fluid flow equations that govern drainage and filtration or the mechanical frameworks that underpin modulus and confinement, geosynthetics help revisit fundamental principles from a slightly different perspective. Including them in geotechnical education not only familiarizes students with geosynthetics but also enhances their understanding of core soil mechanics concepts. In other words, geosynthetics are not just supplementary materials—they act as an effective lens for teaching essential geotechnical concepts clearly and powerfully.

7.4. Highlight the Two-Dimensional Nature of Most Geosynthetics

One of the distinguishing characteristics of most geosynthetics is their two-dimensional shape. Unlike natural soils, which are usually described based on their volumetric properties, geosynthetics are often so thin that their thickness is ignored or included within other parameters. This difference affects how material properties are defined and measured. For example, geosynthetics used for drainage and filtration usually do not report hydraulic conductivity and thickness separately; instead, they report transmissivity or permittivity—properties that include thickness implicitly. As discussed earlier in Section 7.3, this adjustment does not change the fundamental principles, such as Darcy's Law. However, students should understand that geometry and scale affect how those principles are used in geotechnical practice.

Consider again the drainage function. As discussed in Section 7.3, in-plane fluid flow in soils is usually described using Darcy's Law, with hydraulic conductivity (k_p) and layer thickness (t) used to characterize the medium. For thin geosynthetics such as geonets and geocomposites, this principle remains but is adapted using transmissivity (θ), which simplifies the representation by including thickness implicitly. Referring back to Equation 3, this adaptation emphasizes how the two-dimensional nature of geosynthetics influences parameter definition while maintaining key hydraulic principles.

A similar logic applies to the filtration function, which involves cross-plane flow. As described earlier in Section 7.3 (see Equation 5), permittivity (ψ) characterizes thin geosynthetic materials by normalizing cross-plane hydraulic conductivity with thickness. This enables consistent characterization without relying on explicit thickness measurements, demonstrating how geosynthetics adapt classical hydraulic concepts to their physical geometry.

The reinforcement function of geosynthetics offers another opportunity to connect foundational mechanics concepts with geosynthetic behavior. Figure 9 displays the actual slide used to introduce reinforcement concepts in an introductory geotechnical engineering class. Hooke's Law, which governs traditional stress-strain relationships in elastic materials, can be expressed as:

$$\sigma = {}^{F}\!/_{w\,\cdot\,t} = E \cdot \varepsilon \qquad (7)$$

where σ is the normal stress, F is the applied force, w · t is the cross-sectional area, E is Young's modulus, and ε is strain. However, for geosynthetics, this relationship is often reformulated to use "unit tension" (T), defined as force per unit width [F/L], making it more suitable for two-dimensional materials such as geosynthetics:

$$T = J \cdot \varepsilon \qquad (8)$$

Here, J is the tensile stiffness, which equals the product of E and the geosynthetic thickness. By replacing the use of stress (force per unit area) with unit tension (force per unit length), this approach aligns with the two-dimensional geometry of geosynthetics. This transformation helps students bridge familiar concepts from solid mechanics to new applications in geotechnical engineering, emphasizing how dimensionality affects material modeling.

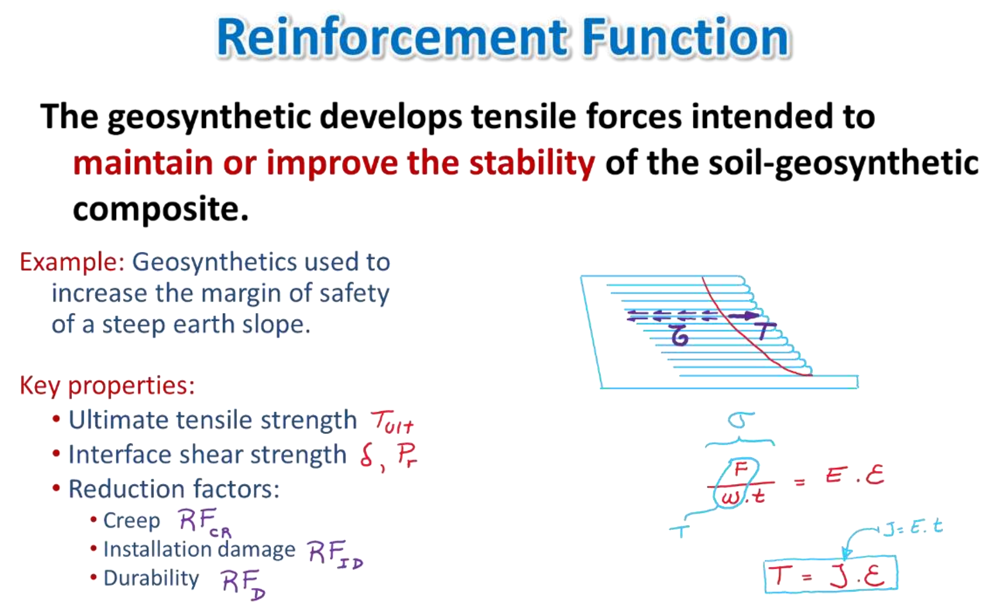

Figure 9. Slide illustrating the reinforcement function in a geosynthetics lecture, focusing on complementing earlier content in a typical introductory geotechnical engineering course

In conclusion, explicitly teaching the two-dimensional nature of geosynthetics helps prevent terminology differences from hiding the fact that the fundamental engineering principles behind the mechanical and hydraulic behavior of soils and geosynthetics are the same. Whether through transmissivity and permittivity in fluid flow or tensile stiffness in reinforcement, geosynthetics continue to use classical laws while adapting them to their unique features. Emphasizing these adaptations promotes a better understanding of how the geometry of geomaterials can influence material characterization, while ensuring that terminology differences do not obstruct the essential knowledge needed for working with both traditional and modern materials in geotechnical practice.

7.5. Revisit the Geosynthetic “Materials” Concepts in Later “Application” Courses

As shown by the survey findings on the state of geosynthetics education in undergraduate geotechnical courses (see Section 5.3), instruction on geosynthetics most often occurs in elective classes, usually focused on geotechnical design applications. This common practice should definitely continue, even as this paper recommends introducing geosynthetics earlier in the curriculum, specifically in the initial course that covers natural geomaterials (i.e., soils). The proposed approach does not replace the vital role of elective, application-oriented courses in reinforcing geosynthetics concepts. Instead, it ensures that when students take these advanced courses, geosynthetics will no longer be their first exposure to the topic.

This sequencing provides a significant pedagogical benefit. Instructors teaching application-oriented topics in geotechnical design won't need to pause to introduce the types, properties, and functions of geosynthetics from the beginning. Instead, these fundamental material concepts will already have been introduced, just as core soil mechanics principles would have been covered earlier in the curriculum. A quick review of geosynthetics—similar to the review often given for shear strength, hydraulic conductivity, or soil consolidation—will be enough to prepare students for more advanced, practical geotechnical subjects.

For example, when teaching the design of earth retaining structures, it would be pedagogically improper to introduce the topic of shear strength for the first time within the design module. Instead, instructors usually assume a working understanding of shear strength and focus on concepts like earth pressure theory and stability. A similar approach applies when discussing reinforced soil structures. Instructors should be able to assume that students are already familiar with the existence of geogrids and the reinforcement function of geosynthetics. Instruction can then concentrate on integrating these concepts into design frameworks—such as internal and external stability of mechanically stabilized earth (MSE) walls—rather than diverting time on basic definitions.

In summary, revisiting geosynthetics in upper-level geotechnical courses enables deeper engagement with their applications instead of just reviewing material fundamentals. This progression mirrors the way soils are treated in the curriculum: introduced early as materials and revisited later in design contexts. Such sequencing aligns with the cognitive framework highlighted in learning research, where spaced repetition and revisiting concepts in varied contexts enhance mastery and long-term transferability (Ambrose, 2020). Integrating geosynthetics into this same pedagogical structure reinforces their role as core geotechnical materials and ensures students are prepared to use them effectively in professional practice.

8. Conclusions and Final Remarks

This paper highlights the urgent need to include geosynthetics in undergraduate civil engineering curricula and offers practical strategies for implementation. Based on both educational principles and institutional realities, the paper shows how geosynthetics—already essential in geotechnical engineering—can be effectively introduced to students early in their academic journey. It recommends presenting geosynthetics as part of the broader family of geomaterials, alongside soils, to ensure that students receive a well-rounded understanding of geotechnical materials and their engineering applications.

A key argument in this paper is that geosynthetics should no longer be treated as peripheral or elective content in civil engineering education. Their extensive use in modern infrastructure, inclusion in design standards, and increasing importance for sustainable engineering practices necessitate their presence in core geotechnical instruction. Introducing geosynthetics early—especially in the first geotechnical class—gives students exposure to new materials and opportunities to strengthen their grasp of fundamental geotechnical principles. The field of geosynthetics includes a wide variety of materials and functions, which presents an educational challenge but also provides a great chance to foster creativity in engineering design. Ultimately, it can be concluded that:

- Because of the breadth in geosynthetics, a successful learning experience will produce professionals who value careful assessment of alternatives to make their best engineering choices..
- Because of the ingenuity of engineering solutions involving geosynthetics, a successful learning experience will produce professionals who value creativity and discovery.

This study involved the development, implementation, and analysis of a comprehensive international survey targeting geotechnical engineering faculty in nine countries—Argentina, Brazil, Canada, Colombia, Germany, Greece, India, Turkey, and the United States—covering both 4-year and 5-year undergraduate degree programs. With an approximate response rate of 72% from 466 identified civil engineering programs, the survey provides a solid and representative overview of how geotechnical education is organized worldwide. It examined the inclusion of geosynthetics in curricula, the structure of required and elective courses, and faculty perspectives on the challenges and opportunities in teaching this subject. The main findings from this study can be summarized as follows::

- The survey received a high response rate—73% overall—across nine countries and 339 civil engineering programs, ensuring strong representation from both 4-year and 5-year educational systems.
- In 4-year programs, over half of the institutions offer at most only one mandatory geotechnical engineering course, and some offer none at all.
- In 5-year programs, such as those in Brazil and Greece, geotechnical engineering is consistently part of the required curriculum, often with multiple courses.
- Across all surveyed programs, over half of future civil engineers do not receive even a single hour of instruction on geosynthetics within required courses.
- When available, coverage of geosynthetics in elective geotechnical courses is typically limited to a few hours, and some programs offer no exposure at all.

Additional findings can be drawn from the implementation of Institutional Tools. Specifically:

- The International Geosynthetics Society (IGS)'s Educate-the-Educators (EtE) initiative has been successful in addressing the lack of faculty preparation, having trained over 800 professors in over 16 countries.
- Follow-up assessments in countries such as Brazil indicate that 60% to 90% of EtE participants incorporated geosynthetics into their courses, with 10% to 17% developing full instructional modules.

Important additional findings can be drawn from the evaluation of the proposed educational strategies to implement geosynthetics in undergraduate curricula, as follows:

- Introducing geosynthetics in the first geotechnical engineering course is expected to ensure that all students, including those not pursuing geotechnical electives, receive foundational exposure to these materials.
- Emphasizing the role of geomaterials as construction materials helps clarify how both natural and synthetic geomaterials are selected, specified, and used in infrastructure systems.
- Drawing parallels between geosynthetics and classical soil mechanics concepts could be identified to enhance the teaching of hydraulic and mechanical behavior by providing relatable, engineered analogues.
- Highlighting the two-dimensional nature of geosynthetics—through concepts like transmissivity, permittivity, and stiffness—may provide a valuable lens for reinforcing core engineering principles in new contexts.
- Revisiting geosynthetics in application-focused courses later in the curriculum allows for deeper engagement with design, rather than requiring remedial instruction on material fundamentals.

Overall, the results from the international survey and the strategies suggested to introduce undergraduate students to geosynthetics indicate a practical and effective pathway that can help modernize civil engineering education. These insights emphasize the importance and practicality of integrating geosynthetics meaningfully into the core curriculum, ensuring that all students—regardless of specialization—are better equipped for the demands of modern geotechnical practice.

Ultimately, the power behind learning geosynthetics may stem precisely from their challenging breadth and their appealing ingenuity. Through this dual lens, students develop not only technical competence but also the capacity to evaluate engineering alternatives critically and creatively.

Acknowledgements

The author gratefully acknowledges the assistance of several colleagues who contributed to the international survey on geosynthetics education by helping identify key contacts and providing relevant information about their respective countries. Special thanks go to Prof. Virginia Sosa (Argentina), Prof. Marolo Alfaro (Canada), Prof. Mario Ramirez (Colombia), Prof. Ennio Palmeira (Brazil), Prof. Gerhard Brau (Germany), Prof. Marina Pantazidou (Greece), Prof. Jagdish Shahu (India), Prof. Nejan Huvaj (Turkey), and Prof. Kristin Sample-Lord (United States) for their invaluable support.

The author also wishes to thank the members of the International Geosynthetics Society (IGS) for their ongoing commitment and collaboration in supporting the Educate-the-Educators (EtE) program. He specifically acknowledges the important contributions of Sam Allen, Augusto Alza, Madalena Barroso, Richard Brachman, Barry Christopher, Ivan Damians, Graça Gardoni, Patricia Guerra-Escobar, Ennio

Palmeira, Marina Pantazidou, Victor Pimentel, Boyd Ramsey, Rosemberg Reyes, and Delma Vidal. The success of the EtE program has been made possible by the dedication of these individuals and many others who have contributed their time and expertise to advance geosynthetics education worldwide.

References

ABET (2022). Criteria for Accrediting Engineering Programs, 2022–2023. Engineering Accreditation Commission. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/

Ambrose, S. A. (2020). Common Instructional Practices Grounded in Evidence. Proceedings of the International Conference on Geotechnical Engineering Education 2020 (GEE2020), June 24–25, Athens, Greece.

Bonilla-Petriciolet, A., Camarena, M.V., Guerra-Sánchez, R. (2021). Engineering Education Reform in Latin America: Challenges and Perspectives. International Journal of Engineering Education, 37(5), 1124–1135.

Damians, I.P., Bathurst, R.J., Adroguer, E.G., Josa, A., Lloret, A. (2018). Sustainability assessment of earth-retaining wall structures. Environmental Geotechnics, 5(4), 231–247.

Gardoni, M.G., Zornberg, J.G., Palmeira, E.M., Touze, N. (2024). An International Initiative on Geosynthetic Education. Soils and Rocks, Vol. 47, No. 2, April, 10 pp.

Giroud, J.P. (2008). Criteria for Granular and Geotextile Filters. Terzaghi Lecture, Geo-Congress 2008, New Orleans, LA, 11 March. https://giroud.geoengineer.org/presentations-videos/asce-terzaghi-lecture

Giroud, J.P., Bonaparte, R. (1989). Leakage through liners constructed with geomembranes – Part II. Composite liners. Geotextiles and Geomembranes, Vol. 8, No. 1, pp. 11-50.

Koerner, R.B. (2012). Designing with Geosynthetics. Sixth Edition. Volumes 1 and 2.

Nguyen, T. T. H., Habók, A. (2021). Educational Reforms and Curriculum Transformation in Higher Education: A Comparative Perspective. Education Sciences, 11(10), 611. https://doi.org/10.3390/educsci11100611

Pantazidou, M. (2023). Personal communication, Athens, Greece, 05 October.

Touze, N. (2021). Healing the World: A Geosynthetics Solution. Geosynthetics International, Vol. 28, No. 1, January, pp. 1-28.

United Nations (2015). Transforming our world: the 2030 Agenda for Sustainable Development. United Nations General Assembly. https://sdgs.un.org/2030agenda

Zornberg, J.G. (2012). Ingenuity in Geotechnical Design using Geosynthetics. Geotechnical Engineering State of the Art and Practice, Geotechnical Special Publication no. 226, ASCE, State-of-the-Art lecture at the Geo-Congress 2012, Oakland, California, March, pp. 398-419.

Zornberg, J.G. (2013). The International Geosynthetics Society (IGS): No Borders for the Good Use of Geosynthetics. 25-Year Retrospectives on the Geosynthetic Industry and Glimpses into the Future, Twenty-fifth Geosynthetic Research Institute Conference (GRI-25), April 01-02, Long Beach, California, pp. 342-357.

Zornberg, J.G. (2017). Geosynthetics in Roadway Infrastructure. Procedia Engineering, Elsevier, Transportation Geotechnics and Geoecology, May, Vol. 189, pp. 298-306.

Zornberg, J.G., Touze, N., Palmeira, E.M. (2020). Educate the Educators: An International Initiative on Geosynthetics Education. Proceedings of the International Conference on Geotechnical Engineering Education, GEE2020, June 24-25, Athens, Greece, 10p.

Zornberg, J.G. (2021). Introduction to Geosynthetics. Educate the Educators Program. International Geosynthetics Society (IGS). Available at: https://www.geosyntheticssociety.org/ete-introduction-geosynthetics-students/

Zornberg, J.G., Subramanian, S., Roodi, G.H., Yalcin, Y., Kumar, V.V. (2024). Sustainability Benefits of Adopting Geosynthetics in Roadway Design. International Journal of Geosynthetics and Ground Engineering, Springer, Vol. 10, May, 27 pp.

Author's Bio

Jorge G. Zornberg, The University of Texas at Austin (USA)

Dr. Jorge G. Zornberg has over 35 years of experience in the practice and research of geotechnical and geosynthetics engineering. His research focuses on transportation geotechnics, environmental geotechnics, geosynthetics, unsaturated soils, and expansive clays. As an engineering consultant, he has served as an expert witness in litigation and forensic geotechnical cases. From 2010 to 2014, he was President of the International Geosynthetics Society (IGS). He has authored over 550 technical publications, contributed to several book chapters, and holds three patents. Prof. Zornberg has received numerous prestigious honors, including the Ralph B. Peck Award, Croes Medal, and Collingwood Prize from ASCE; the Mercer Lecture Award from ISSMGE and IGS; and the IGS Service Award, IGS Award, and Young IGS Member Award. He was also the recipient of the Presidential Early Career Award for Scientists and Engineers (PECASE) from President George W. Bush. In 2019, the IGS established the "Zornberg Lecture," an honorary lecture recognizing his outstanding contributions to the geosynthetics discipline.