In Search of Approaches to Embed Teaching of Geosynthetics within the Curriculum: Filling an Educational Gap

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ABSTRACT: In this paper, we present lessons learned from the application of a set of activities aimed at introducing knowledge about geosynthetics within the existing curriculum of a geotechnical engineering course at a South African university. We explain how students were exposed to the multiple functions and benefits of geosynthetics, through a combined approach of selected readings, problem solving activities, physical models for class demonstrations, a guest lecture by an invited industry professional, and a group assignment. The students' experiences of this program were evaluated using a qualitative survey instrument.

Keywords: geotechnical engineering education, geosynthetics, student engagement

1 Introduction

Geosynthetics is among the most important innovations in geotechnical engineering in the second half of the 20th century (Giroud, 2006). These products have become pervasive in geotechnical engineering, to the extent that it is scarcely possible to practice geotechnical engineering without the use of geosynthetics. Geosynthetics play a role in mitigating many of the global crises facing society today, by improving water quality, protecting the environment, recovering from natural disasters, providing economically-viable solutions, and supporting a sustainable future.

The use of geosynthetics is even more vital in Africa, which is affected by climate change in the form of long periods of drought and more frequent extreme weather events. Expansive lateritic soils, collapsible soils and dolomitic ground leading to sinkhole formation are just a few of the geotechnical problems that can be treated effectively using geosynthetics. In addition, extensive mining activity, and support of road, railroad and bridge networks necessitate more regular use of geosynthetics in the design of geo-engineered structures. A geosynthetic solution provides more guarantees for a sustainable future, particularly regarding water transport systems, preservation of the quality of fresh water, erosion control, crop protection and urban agriculture.

In this paper, we present and investigate an approach to introducing geosynthetic engineering into a geotechnical engineering course in a South African university. We explain how students were exposed to the multiple functions and benefits of geosynthetics, selected readings, group assignments, problem solving activities, physical models for class demonstrations, and a guest lecture by an invited industry professional and a group assignment. We evaluate these activities by using a qualitative survey instrument. The remainder of this paper is structured such that it begins with an overview of the importance of geosynthetics in geotechnical engineering design, and therefore, of incorporating geosynthetics into the geotechnical engineering curriculum. Thereafter, the methodology deployed is discussed in greater detail before the results of this research are presented and conclusions and recommendations are made.

2 Importance of geosynthetic solutions

A geosynthetic is defined, in the international standard EN ISO 10318 (AFNOR, 2015), as a product where at least one of the components is made from synthetic or natural polymer, in the form of a sheet, a strip, or a 3 dimensional structure, used in contact with soil and/or other materials in geotechnical and geo-environmental applications. Geosynthetics, in various forms, have been used successfully for around 50 years in various applications such as reinforced earth walls, ground improvement, slope protection and stabilisation, sanitary landfill, roads and airport runways, as well as tunnelling. More recently, their use has evolved considerably with the development of new materials and their use is now widespread in geotechnical engineering practice. In Table 1 key functions along with main applications and impacts of geosynthetics are grouped.

Table 1. Summary of functions and applications of geosynthetics

Functions	Applications	Mitigation effect
Barrier	Dams, canals, reservoirs / pipelines	Minimise contamination of municipal solid waste and tailings storage Prevent water infiltration to underground aquifer and gas mitigation from the atmosphere
Drainage	Roadway embankments Pavement edge drains, slope interceptor drain, abutment and retaining walls drains	Pore water pressure dissipation / earth structure stability
Filtration	Drainage aggregate / pipes	Soil migration
Reinforcement	Reinforced soil walls, rod and railways, landfills, or bridging sinkholes Reinforced Embankments	Failure, earthquake loading, settlement and settlement differences
Separation		Surface runoff
Surface Erosion control	Coastal lines	High waves, high tides, multiple storm events

Because of their high strength and durability, geosynthetic technologies are broadly used to mitigate the effects of natural disasters and protect against the impact of climate change. Examples include reinforced embankments that resist overtopping induced by tsunamis and river flooding, and reinforced soil walls and/or geo-nets for rock fall protection.

Despite all of these benefits and applications, the International Geosynthetics Society (IGS) (2019) indicates that graduating engineering students often have little or no exposure to appropriate use of geosynthetics in engineering practice. In North America, for example, only 45 university engineering programmes include geosynthetics education in their curricula. As such, a major goal of the IGS Council is to ensure that “geosynthetics become indispensable to the point that they are regularly included in engineering curricula and relevant design standards”. Moreover, a specific objective has been to “introduce geosynthetic education at the undergraduate level”.

Some programmes introduce geosynthetics by way of a 14-week-long module on “Geosynthetics in Geotechnical Engineering”, offered at Master’s level, for example in the USA, Portugal, France, India (Gabr, 2019; Pinho-Lopes, 2018). In South Africa, “Geosynthetics Engineering” is one of the elective modules offered in a coursework Master’s program specialising in geotechnical engineering offered by the University of Cape Town. The current practice in a majority of South African universities, at undergraduate level, is to invite guest lecturers to present case studies and products to third or final year students. We argue that this model can prove to be less effective, as students are often overwhelmed by the plethora of products and materials, thus failing to focus on and understand the basic functions and benefits of geosynthetics. In this paper, we seek out methods to introduce a structured, formative and student-centred approach to introducing geosynthetic engineering to undergraduate students. The rationale is to develop a curriculum where more emphasis is given to geosynthetic engineering, since graduate skill needs to be aligned with current engineering practice and needs.

3 Methodology

The Civil Engineering programme under study in this paper is a four-year programme, consisting of eight semesters, and includes an overall credit value of 604 credits with the requirement of successful completion of 46 modules. The first two years of the programme primarily include introductory modules that present the foundations of mathematics, the natural sciences, and engineering science. The third year of the programme includes core engineering science modules across several specialist areas, such as structural engineering, geotechnical engineering, transportation engineering, hydraulic engineering and environmental engineering. Geotechnical engineering education includes two semesters of Geotechnical Engineering at 3rd year level and one semester in Foundation Engineering at 4th year level. Basic elements of project management are also introduced in the third year. The first semester of the fourth year develops the aforementioned specialist areas as well as project management, while the second semester of the final year is almost entirely devoted to two capstone courses in research investigation and engineering design. The current structure of the program does not include electives.

The purpose of this research was to develop and investigate a pedagogical process aimed at exposing students to the value of geosynthetics in geotechnical engineering practice. This pedagogical process was conducted over a number of weeks during the third-year modules in geotechnical engineering. It entailed a combination of problem solving, a guest lecture on the use of geosynthetics in geotechnical engineering practice presented by an industry colleague, and selected reading from the literature. The guest lecturer presented case studies on slope stabilisation, basal reinforcement, applications in pavement engineering, and construction of high walls in urban and mining environments. Students observed a practical lecture demonstration on calculation of slope stability – with and without reinforcement and they were asked to solve a relevant problem as a small, in-class assignment. Later, students were required to complete a survey pertaining to their perceptions of and attitudes towards the applications of geosynthetics in geotechnical engineering.

3.1 Student engagement in class activity involving geosynthetics

A classic example from the 8th edition of Craig's Soil Mechanics (Knappett & Craig, 2012) was used in order to illustrate the effective use of geosynthetics in accelerating the rate of consolidation. Another problem was given to demonstrate the effect of geosynthetics on increasing the slope stability factor of a fill embankment. This was done as per the recommendation of Stark (2018), made during the Educate the Educators programme offered by the IGS & Geosynthetics Interest Group of South Africa (GIGSA) in July 2018, namely, that it is advisable to incorporate geosynthetics in existing lectures rather than creating standalone lectures on geosynthetics. In this way, students may be exposed to a range of diverse applications.

The first selected application pertained to the drainage function. The students had been taught about consolidation for almost four weeks and were also shown a video on the application of prefabricated vertical drains. The students were given a problem from Craig's Soil Mechanics (example 4.7 on p. 139) which required them to calculate the settlement of fine-grained soil due to consolidation and to show how the consolidation is accelerated through the use of prefabricated vertical drains.

First, the students needed to calculate the final settlement of the clay layer under the large fill. They then needed to compute the settlement after 3 years, and the required time for 95% of the consolidation to occur (which was found to be 9 years). Thereafter, the students had to determine the spacing of 100mm diameter sand drains in order to ensure that all but 25mm of consolidation settlement would occur within 6 months of placement of the embankment. The correct answer for the final settlement was found to be 2.4m. Finally, the students had to repeat the calculations using a square pattern of 400mm diameter sand drains to find that the spacing would increase to 3.2m.

The second selected application was a problem where the students had to consider a specific cross-section through a slope and formulate an expression for the factor of safety, as shown in Figure 1.

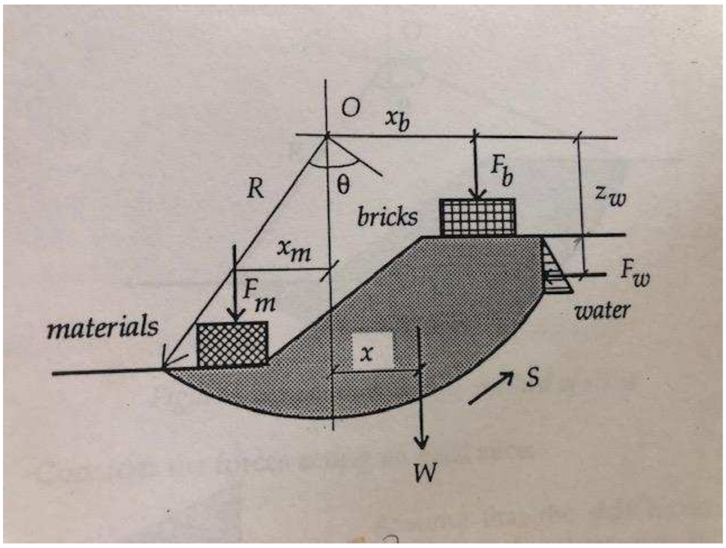

Figure 1. Cross section of slope stability problem

A reduced scale model was used in order to more effectively demonstrate the repose angle, and calculate the safety factor for the small-scale, classroom model. Thereafter, the students were asked to formulate an expression of the safety factor for various scenarios: dry, or undrained conditions, and loading after having installed a series of geosynthetic layers in the model at a specific spacing.

Figure 2. a) Slope model that served as a classroom model in order to show the repose angle of the dry sand slope, b) demonstration of function of reinforcement through the use of the small-scale model slope

It was observed that the students appreciated the effect of geosynthetic engineering in both applications, as they proved through their calculations the benefit of each solution. However only half of the class engaged in the first problem solving activity, and one third of the class attended the class demonstration and problem solving activity on slope stability analysis. It was also remarkable that when they were asked as part of the survey on the application of geosynthetics, none of the students referred to the acceleration of consolidation rate.

3.2 Survey design

In order to investigate the outcomes of this pedagogical process, several types of data were collected and analysed. Firstly, the students' completion of the example problems was observed with a view to investigating the extent to which they were able to demonstrate how the use of geosynthetics could assist in preventing slope failure or accelerating consolidation time.

Secondly, the results of the student survey were analysed in terms of the students' perceptions of and attitudes towards geosynthetics, after having gone through the pedagogical intervention described. These survey results provide insight into students' misconceptions surrounding geosynthetic engineering – as well as their intentions to utilise geosynthetics in the future. This final point – intention to use geosynthetics in the future – was correlated with students' actual use of geosynthetics in a design project that the students undertook during the course of the semester. This design project was intentionally open-ended, and students were not required to use geosynthetics.

The survey and student presentations and reports were analysed using the techniques of content analysis. Content analysis is a data analysis strategy that turns qualitative data into quantitative data through a process of counting the number of appearances of particular content. This is done through a process of coding, or "systematic, objective, quantitative analysis of message characteristics" (Neuendorf, 2002). Content analysis has been applied to a wide and diverse range of research interests, particularly in linguistics and media studies. In this research, it was used to identify what the sampled student group identified as most salient in their thinking about geosynthetics.

All students whose participation is reported on herein gave written and informed consent for their participation to be included in this research. This includes their design projects as well as the surveys they completed. Students had the option to refuse to participate in this research – without any adverse repercussions. Moreover, they could withdraw their participation at any point during the research process.

4 Results and Discussion

4.1 Student perceptions and attitudes towards geosynthetics: Survey results

The survey included three yes/no questions: students were asked to anonymously indicate whether they had done the prescribed reading on geosynthetics, whether they had attended the guest lecture, and whether they had or would consider geosynthetics as a possible solution in the design project they were required to complete in the same semester. In this regard, all but four students admitted that they had not read the prescribed text. Of the four who had, two indicated that they had only read parts of the prescribed reading. In contrast, all but four students who completed the survey had attended the guest lecture. Two students indicated that they had attended the guest lecture and that they had read at least part of the prescribed text, while two students said that they had done neither. Regarding the third question (whether they had or would consider using geosynthetics in their design project), only one student said they would not consider or had not considered using geosynthetics in the future.

Thereafter, the survey consisted of four open-ended questions below:

1. How would you define geosynthetics?
2. What is the value/role of geosynthetics in the work of a geotechnical engineer?
3. What kind of geotechnical engineering problems/challenges do you think geosynthetics can address/solve?
4. Comment on your likelihood to use geosynthetics in future (please elaborate on your answer)

The first question was aimed at ascertaining the students' understanding of the concept. Before analysing this question, we identified four key aspects of a definition of geosynthetics.

a) At its most basic, geosynthetics are a family of materials or products.
b) These materials are synthetic or, more accurately, polymeric.
c) The materials are in sheet form.
d) Geosynthetics may either have an open structure and provide high tensile strength, or are closed sheets used as impermeable drainage barriers.

In this regard, of the 52 students who completed the survey, 49 were able to identify the last aspect of the definition, that is, the function of geosynthetics. It should be noted that a majority of these noted the function of slope reinforcement, which was the function foregrounded in the project, in the guest lecture, and in the problem-solving exercise, but is not the only function of geosynthetics. Also, 45 students identified geosynthetics as constituting a family of materials or products, but only 31 included the polymeric or synthetic nature of geosynthetics in their definition. Only five students referred to the planar form of geosynthetic materials. This means that while few students were able to provide a comprehensive definition of geosynthetics, a large majority were at least aware of the materiality and function of geosynthetics.

Nonetheless, there were some misconceptions evident in the definitions provided. For example, one student argued that geosynthetics “is the study of geotechnical engineering which is based on determining way[s] to … stabilize soil generally”, and another suggested that “it is the science [of] making slopes to be more stable, by using methods that makes the FS to be above 1 and design slope that would not fail”. A third student contended that geosynthetics “are materials that are used to stabilize any slope *upon failure*” (emphasis added). The first two examples here suggest that the students confuse geosynthetics as products with the engineering, through the study of soil mechanics, in which these products are deployed. The third example fails to appreciate that geosynthetics are not only used for rehabilitation where failure has occurred (though this was the focus of the design project and of some aspects of the guest lecture) but can also be used in the initial design solution.

The following two questions of the survey asked students about the role, or value, of geosynthetics in geotechnical engineering design and about the kinds of geotechnical engineering problems, or challenges, that could be addressed, or mitigated by using geosynthetics. There was significant overlap in the responses to these two questions and, as such, they were analysed together. The responses to these two questions broadly fell into two broad categories: the applications of geosynthetics and the advantages of using geosynthetics. Regarding the applications of geosynthetics, the student participants identified various applications of geosynthetics, ranging from general applications to more specific or specialised applications. Table 2 provides a summary of the content of the responses obtained, as well as an indication of the number of students that raised that particular point in their response to one or both of the two questions. Regarding the advantages of geosynthetics, the student participants identified several advantages; these are listed in Table 3.

Table 2. Survey results regarding applications of geosynthetics

Application identified in students' response	Function according to IGS nomenclature	Frequency of response
Slope stability	Soil reinforcement	31
Soil reinforcement	Soil reinforcement	28
Erosion protection	Erosion control	24
Slope failure and rehabilitation	Soil reinforcement	18
Filtration/Drainage/Seepage	Filtration / drainage	12
Preventing infiltration/ingress of liquids	Barrier	8
Retaining walls and backfill	Soil reinforcement	7
Landslide protection	Erosion control/soil reinforcement	6
Seismic protection	Soil reinforcement	2
Rock falls	Erosion control	2
Settlement	Drainage	1
Underwater foundations	?	1

The final question in the survey asked students to comment on the likelihood of them using geosynthetics in the future and to elaborate on their answer. To this end, the vast majority of students indicated that they would use geosynthetics and a quarter of the respondents suggested that they were “very likely” or would “strongly consider” or “definitely” use geosynthetics in the future. In most instances, the student participants cited the previously listed advantages of geosynthetics as the reason for their answer. However, there were some students who tied the use of geosynthetics specifically to their future career goals and aspirations. For example, one student stated: “I will most probably use geosynthetics in the future for I am looking to further my career in geotechnical engineering”. Another was even more specific about their future career plans: “chances are that after graduation I will work in a mining company which is open cast. The slope stability of the mine will be very important, hence I will use the geosynthetics to improve the slopes while the mining is operating and also for the haul roads in the mine”.

Table 3. Survey results regarding advantages of geosynthetics

Advantage	Frequency of response
Reduced cost (particularly regarding material replacement)	10
Overcoming the limitations of natural materials	8
Increased/high tensile strength	8
Reduced settlement and increased bearing capacity	6
Easy handling and use	6
Improved (minimised) permeability	5
Enabling design of steeper slopes	4
Increased Factors of Safety	3
Pore water pressure reduction/hydraulic pressure dissipation	3
Reduced labour	2
Reduced CO_2 emissions	1
Variety of types and applications	1
Reduced material volumes	1
Durability	1
Promotion of vegetation	1
Reduced time	1

Yet, some students were less enthusiastic in their responses. One student suggested that they would use geosynthetics if the need arose, but that their interest in geotechnical engineering was minimal. Finally, one student provided a particularly pragmatic, but insightful answer to the question by arguing that they would be very likely to use geosynthetics "depending on the situation, location, and other alternatives as well as the customer".

4.2 Students' design with geosynthetics

During the semester over which this study was conducted, the students were also required to complete a mini-design project, which required them to propose a design solution for road slip repair where failure was induced due to the combined effect of erosion and seepage and poor in-situ fill materials (Simpson & Ferentinou, 2020). The students were not required to pursue any particular solution and the design problem was entirely open-ended. The design project was undertaken in groups of three or four students. Many groups opted to incorporate geosynthetics into their design project – even before the guest lecture and the specific input on geosynthetics was provided. However, their initial design solutions (proposed before the guest lecture and before the survey discussed above was administered) suggested numerous misunderstandings and misconceptions about both geosynthetics and slope failure more generally.

For example, while many groups used RocScience to design geosynthetics into their proposed solution, only a small number (fewer than 5, out of more than 20), placed their geosynthetics horizontally. Instead, most groups' designs saw the geosynthetic materials placed perpendicular to the slope face, revealing a lack of understanding of the process of installing geosynthetics or a lack of thought given to constructability. In addition, most groups did not extend the geosynthetic layers into the slope such that the geosynthetic materials intersected the slip failure surface. This suggested a lack of understanding of the purpose of geosynthetic materials and a lack of understanding of the mechanics of slope stability. However, it is not entirely expected from 3rd year students to be able to consider the overall stability of the slope soil bodies whose failure planes cut the reinforcement layers, in addition to those bodies which include the reinforced earth body (Figure 3) or the tensile forces required for the overall stability.

Because of this failure to extend the geosynthetic materials into the slope, many groups, even after adding geosynthetic layers into their design, failed to obtain a satisfactory factor of safety. As a consequence, they reduced the slope angle, which resulted in more space being utilised in the design, and the geosynthetic materials effectively being wasted. This again highlighted the students' lack of understanding of the mechanics of slope failure and their misrecognition of the advantage of geosynthetics that some of them subsequently raised in the survey results, namely, steeper slope design and the concomitant benefits of reduced space utilisation and reduced materials requirements. Also, because the students did not extend their geosynthetic layers into the slope, they needed to include numerous layers with spacing of, in some instances, only one metre. This resulted in expensive over-design, and again highlighted the shortcomings in the students' understandings both of the mechanics of slope failure and of the purpose and value of geosynthetics within geotechnical engineering design. In some cases, these misconceptions had been ironed out by the final design presentations, but in many, they remained evident even in the final design presentations.

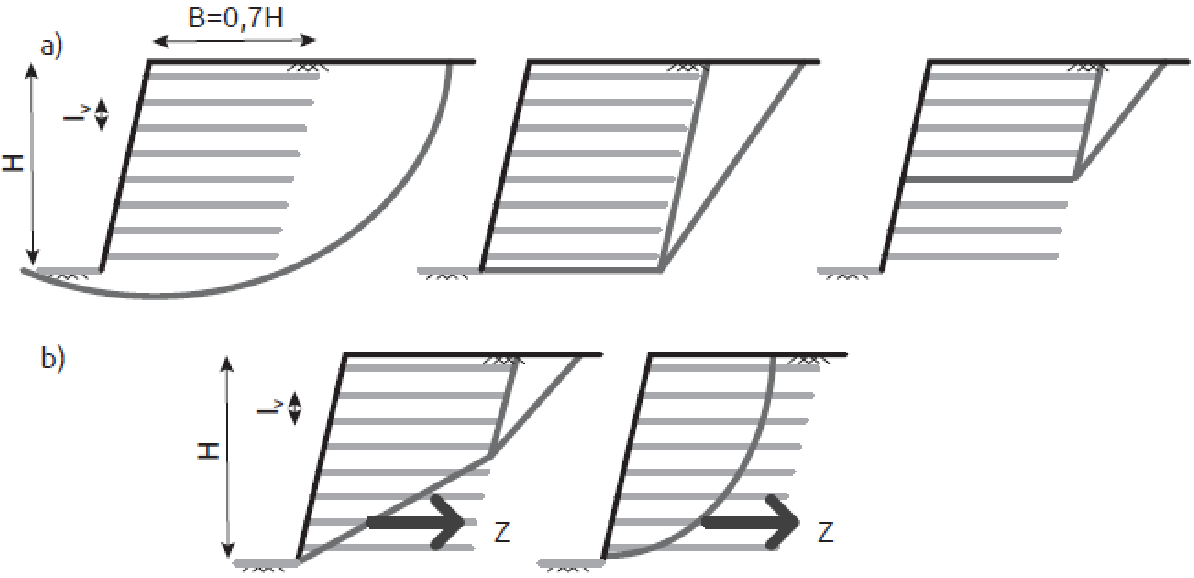

Figure 3. Slip planes for the verification of overall stability: a) outside and/or along the reinforcement layers; and (b) which intersect the reinforcement layers (adapted from Ziegler, 2018)

5 Conclusion

This paper has presented an approach to the integration of geosynthetics into a geotechnical engineering module that forms part of a civil engineering degree programme. As argued by the International Geosynthetics Society, graduating engineering students have little or no exposure to the appropriate use of geosynthetics in engineering practice. To address this issue, in this paper, we present an example and lessons learned of how the core principles of geosynthetics can be incorporated into the existing curriculum. As part of this approach, we proposed a combination of lectures, demonstrations, class problems, and a mini-project which provided a project-based approach to our teaching method.

As was seen in the results obtained, in both the in-class problem and in the survey results, students were able to do quite well in terms of explaining the functions and applications of geosynthetics in theory. Moreover, they demonstrated significant intention to use geosynthetics in the future. However, their actual use of geosynthetics, as evident in the design project, showed that they still held various misconceptions about the application of geosynthetics in practice.

The authors' reflection after the application of the proposed activities, is summarised as follows:

- There is a need to make reading selected literature on geosynthetic materials compulsory, through relevant assessment quizzes, or small tests.
- It is necessary to dedicate more time, though a series of formative lectures, to the functions and applications of geosynthetics, perhaps in the form of a workshop, as this would require more contact hours outside the formal timetable.
- It may be useful to develop one small project where the elements of design with geosynthetics are scaffolded and developed, so that the students get sufficient exposure to the elements of the design of one particular application. To this end, the support of the local IGS chapter (GIGSA), will be a significant benefit to the students.

Nonetheless, these practical challenges can be resolved through a greater number of tasks that require use of geosynthetics and, ultimately, through several years of practical work-based experience in using such geosynthetics. The ultimate benefit of these efforts would be in the form of engineering graduates with an applied knowledge of geosynthetics who can contribute to mitigating many of the negative impacts of geotechnical engineering practice.

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