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Historical aspects and challenges of teaching engineering geology to engineering students

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Article

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Abstract

This paper discusses some points of the evolution of Engineering Geology based on a survey of historical facts, books, and other types of publications and technical reports and analyzes the teaching in engineering schools, specifically in the São Carlos School of Engineering, at University of São Paulo (EESC/USP). The survey involved the main topics considered in the teaching of Engineering Geology and both successes and challenges of the teaching experience at undergraduate and graduate levels at EESC/USP over the past 50 years are presented. Engineering Geology teaching has undergone different phases and adaptations to the evolution of knowledge and research procedures. According to the survey, it focuses on four large groups of didactic activities for the current decade and, perhaps, for the next one in several countries. The first group refers to access to materials of each topic in the format of books, videos, and lectures available on websites and the second includes face-to-face activities on the solution of practical problems related to a specific topic. The third group focuses on field and laboratory works, whereas the fourth comprehends development and analyses of specific civil work projects, mineral exploration, and environmental problems according to both face-to-face and non-face-to-face methodologies.

1. Introduction

Engineering Geology has been developed over the past 150 years in many countries and taught to students of Geology and Geological, Civil, and Mining Engineering courses, more effectively from the 1950s onwards, and to those of Environmental Engineering over the last 25 years. Records of Engineering Geology teaching were already kept at American universities in the last years of the 19th century (*e.g.*, a set of pioneering works published by William O. Crosbi - MIT and James F. Kemp - Columbia) in 1890 on the importance of the relationship between aspects of Geology and construction procedures of significant engineering works. Term Engineering Geology was introduced in the middle of the 19th century in several European countries and its name in Portuguese derived from the general translation of the following terms: Engineering Geology (English), Ingeniería Geológica (Spanish), InzhenernayaGeologiya (Russian), Géologie de l'ingénieur (French), and Ingenieurgeologie (German). In the first half of the 20th century, Engineering Geology spread more intensely in North America and Europe, but with special characteristics in each country or region, depending on their needs, such as types of engineering works or specific land use problems. Currently, Engineering Geology, along with Soil and Rock Mechanics, constitute the basis of the field of knowledge called Geotechnics (Krynine & Judd, 1957; JEWG, 2004; Giles, 2005). However, the relationships among the three areas of expertise vary from country to country. According to Müller-Salzburg (1976), Engineering Geology emerged as an independent field of knowledge (IDENTITY), generating quantitative information on geological facts necessary for engineering and mining projects to avoid problems during their execution and valuable life. On the other hand, technical terms currently used for the characterization and description of geological materials in aspects related to Engineering Geology can be found since the Mycenaean Civilization, as described in several publications. Zekkos et al. (2006), Morgan Stanley (2015), and Field (2018) discussed Engineering Geology in Homer's poems (HOMERIC POEMS), which also introduced the conceptual aspect of term risk in the epic poem Odyssey, which is still valid and applied in the most different areas of knowledge. However, Leonardo da Vinci's works (1452 - 1519) led several researchers (Olson & Eddy, 1943; Jones, 1962; Martínez Frías & Martínez Martín, 2023) to consider him the first practitioner of "applied geology" for environmental analyses and engineering works. Engineering Geology was first coined by William Smith (1800 to 1815), in England, in canalization projects in mining areas, and the study is considered the first geotechnical/engineering geological map and one of the bases of modern Geology by an influential group of professionals. Over the past 150 years, it has spread to different countries and the definitions provided have led to changes towards their adaptations to advances in technical and

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scientific knowledge involving Geology, Civil, and Mining Engineering and interrelated areas of expertise. After 1990, their adaptations were related to environmental problems, when Environmental Engineering emerged. The definitions provided below are considered the most cited ones and have guided associations and schools in different countries in training professionals. One of the oldest, i.e., the science that involves all aspects of geology and is important in the planning, design, construction, and maintenance of engineering structures, was proposed by Popov (1959), the founder of Soviet Engineering Geology. Komarov (1967) modified it by considering some conditions of the natural environment; whereas Sergeev (1978) added the viewpoint of some aspects of human activities. Currently, Engineering Geology is defined in the statutes of International Association for Engineering Geology and the Environment (IAEGE) as the science devoted to the investigation, study, and solution of engineering and environmental problems which may arise from the interaction among geology and the works or activities of man, as well as from the prediction and development of measures for the prevention or remediation of geological hazards. In general, Engineering Geology teaching has followed the evolution of knowledge in several topics and the insertion and use of technological resources developed for different areas of knowledge and that enable improvements in field and laboratory investigations. In the first period, which covered the mid-nineteenth century up to the 1950s, teaching focused more on geology for engineers, with an approach to fundamental geology topics such as minerals, rocks, geological structures, and geological maps, and more directly on the use of rocks as construction materials in dams and tunnels. The second period, between 1950 and 1980 and from 1950 onwards, Engineering Geology significantly expanded and its teaching was already consolidated in several universities of many countries. During that period, Brazil witnessed an intense development in dam construction and both engineering and geology schools incorporated various aspects of design and construction, advancing the knowledge and teaching of Engineering Geology. The third period encompassed the 1980 and 2000 and, in 2000, an important technical-scientific event took place in Australia involving the International Association of Engineering Geology and Environment (IAEGE), International Association of Rock Mechanics (ISRM), and ISSMGE (International Society for Soil Mechanics and Geotechnical Engineering), which discussed the insertion of the three primary areas of Geotechnics under term “Common Ground”. Since then, its teaching has aimed at maintaining a more significant interaction with that of Soil and Rock mechanics. The fourth period, which covers the years from 2000 up to the present day, includes new topics such as models, spatial variability, uncertainties, and statistical methods applied to different aspects of Engineering Geology, and a substantial increase in environmental issues within its teaching.

However, Engineering Geology teaching has always faced challenges in both theoretical and practical aspects, due to the need to adapt teaching to the amount of new knowledge available, technological resources, professional demands, and relationships with statistical and mathematical resources. The theoretical sense refers to the supply of a perceptive understanding of rocks, minerals, geological structures, and geological processes to students and establishment of a basis for the understanding of how geological aspects positively or negatively affect engineering works and control of environmental conditions. In practical and experimental teaching, the challenges are related to laboratory conditions for identification and characterization of geological materials, geological and engineering maps on appropriate scales, equipment for unconsolidated and rock material testing, availability and authorizations for the use of data from construction sites, software for different purposes, and, especially, field activities. Difficulties concern budgets of educational institutions for educational fieldtrips, fieldwork and visits to engineering works and areas under environmental problems, purchase of software and computers, and rooms with multidisciplinary resources for teaching.

This study evaluated some points of the evolution of Engineering Geology based on a survey of historical facts, books, and other types of publications and technical reports and analyzed teaching in engineering schools, specifically in the São Carlos School of Engineering, at University of São Paulo (EESC/USP).

2. Brief historical

The following brief historical aspects are presented for supporting the understanding of advances in the teaching of Engineering Geology according to some specific points related to its development. A complete set of facts and publications in a chronological order about the beginning and advances of Engineering Geology and a full text on historical aspects can be found in Ribeiro et al. (2023).

The advances and development of Engineering Geology can be divided into different periods, of which the first encompasses part of the 18th and 19th centuries. In 1725, John Strachey developed a set of vertical cross sections to assist in the opening and excavation planning of Somerset mine (England) and in 1879-1880; W. H. Penning published the book Engineering Geology. Between 1799 and 1815, William Smith developed several works in England and a geological map to help the implementation of canals (http://earthobservatory.nasa.gov/IOTD/view.php?id=8733), which can be considered the first Engineering Geological Map. Important facts of the second period (between 1900 and 1925) included launching of several texts and books and, around 1906, publication of several versions of the London subsoil map by Woodward, towards guiding the planning of sanitation works. In the third period, between 1925 and 1950, among the several books published were Engineering

Geology, authored by Redlich, Terzaghi and Kampe, and A Comprehensive Treatise on Engineering Geology, by C.S. Fox. In 1935, K. Terzaghi published the text "Effect of minor geological details on the safety of dams". In 1928, St. Francis dam collapsed in California (USA), killing more than 450 people and causing above 9 million-dollar losses, thus accelerating the implementation of Engineering Geology in the USA, with Charles Berkey as its exponent. During the fourth period, between 1950 and 1970, Engineering Geology teaching in universities was strengthened. In 1957 (London-England), the first graduate course in Engineering Geology was created at Imperial College, led by John Knill and open to geologists and engineers. In Brazil, the first Geology courses were created at Federal University of Rio Grande do Sul (UFRGS), University of São Paulo (USP), Federal University of Rio de Janeiro (UFRJ), Federal University of Pernambuco (UFPE), and Federal University of Ouro Preto (UFOP) and were fundamental for the training of professionals in the field of engineering geology and the creation of engineering geology disciplines in civil and mining engineering courses. Several essential publications can also be highlighted in this period (e.g., the book "Geology in Engineering", published by John Russell Schultz (1955), with many editions until the end of the 1980s and considered an important bibliographic reference to date, and the text "The Vaiont Tragedy: geologic causes and engineering implications", by G.A. Kiersch (1965), about the Vaiont disaster.

The fifth period, which encompassed 1970 to 2000, witnessed the greatest technical-scientific advances and those related to development, disseminated in several international and national congresses in several countries. Many books and didactic texts were published, culminating in an event in Australia, in 2020, involving IAEGE, ISRM and ISSMGE associations. At the event, Morgenstern discussed and gave a lecture on "Common Ground", a term that encompasses the integration of the three basic areas of Geotechnics.

During the sixth period, beginning in 2000 and continuing to date, IAEGE held the 9th International Congress of Engineering Geology in Durban (South Africa), in 2002, and whose main theme was Engineering Geology for developing countries. Knill (2002) held The First Hans-Cloos Lecture - Core Values for Engineering Geology, which led IAEGE to promote debates on the topic. In2004, a set of issues considered Core Values, which serve as guidelines for teaching and training professionals, was published in IAEG News (Vol. 32, No 1, 2004).

Culshaw (2005) published the text "From Concept towards Reality: developing the attributed 3D geological model of the shallow subsurface", addressing a fundamental theme for the understanding of the spatial variability of geological materials and geological structures, which gained ground in that decade due to advances in computational techniques. In 2006, H. Bock published the text "Common Ground in engineering geology, soil mechanics and rock mechanics: past, present and Future", which points to future paths to be followed by the three primary areas of Geotechnics.

Among all aspects discussed by Engineering Geology over the past 10 years, two stand out: uncertainty assessments in the prediction of hazardous events and associated risks, whether related to engineering works, restoration of degraded land or prognostic of environmental problems, or natural processes and analyses in 3D/4D models. Over the last 20 years, many books on Engineering Geology with contents related to new approaches and uses of technological, statistical, and mathematical resources have been published (Ribeiro et al., 2023).

3. Development of Engineering Geology teaching

Engineering Geology teaching can be analyzed in a few periods, according to the topics taught in different countries, at both undergraduate level in civil, mining, and environmental engineering courses and graduate level, and the course content is usually reflected in several textbooks published.

The period between the mid-19th century and the 1950s can be considered the first. Teaching focused mostly on geology for engineers, covering the fundamental topics of geology, such as minerals, rocks, geological structures, and geological maps, and more directly on rock used as construction materials and in some engineering works, such as dams and tunnels.

From 1950 up to 1980, the second period, Engineering Geology expanded substantially. The book authored by Krynine and Judd was published in 1950 and addressed the interaction between Engineering Geology and Soil Mechanics, as well as the context of Geotechnics. In many countries, Engineering Geology teaching was already consolidated in several universities. The urbanization process also intensified and Engineering Geology aimed to adapt to data generation for urban area territorial and environmental planning. The first IAEG congress was held in Paris, in 1970 and, in Brazil, due to the intense development of dam construction, teaching in engineering and geology schools incorporated several aspects of design and construction.

In 2000, a technical-scientific event involving IAEGE, ISRM and ISSMGE associations took place in Australia and discussed the meeting of the three primary areas of Geotechnics as a function of the term "Common Ground". A lecture on "Common Ground" was delivered by Morgenstern and one on "Total Geological History: A model approach to the anticipation, observation and understanding of site conditions" was given by Fookes, Baynes & Hutchinson. The event involved other proposals, resulting in the term "Ground Engineering", coined by JEWG (2004). Since then, the teaching of Engineering Geology has aimed at a closer relationship with that of Soil and Rock Mechanics.

The fourth period, from 2000 onwards, has considered new topics, such as 3D-4D models, spatial variability, uncertainties, and statistical methods applied to the different aspects of Engineering Geology, all of them parts of books and texts published and of an interesting overview provided by Griffiths (2014) and Oliveira (2009).

4. Current themes in Engineering Geology teaching

The main subjects of Engineering Geology disciplines for engineering courses at universities in different countries, taken from references and texts published since the beginning of the 20th century, are provided in the supplementary materials (Ribeiro et al., 2023) and texts that are fundamental references for the understanding of advances in both technical and scientific development and teaching can be found in Appendix 1.

Such subjects can be adopted according to regional aspects and specific objectives of the country and the course, whether Civil, Mining, or Environmental Engineering, and taught in different disciplines or segments in function of each educational institute's characteristics and teaching conditions. Practical activities can be developed in classroom, laboratory, or field. Engineering Geology disciplines can emphasize local or regional subjects, depending on the country or region – as an example, based on the climate zone of their country, educational institutions can adopt different topics due to variations in the types of regolith, which are thicker in tropical climates and thinner in cold ones, with or without presence of permafrost. Other examples are the educational institutions in regions with heavy mining, such as the schools of Minas Gerais and Pará, in Brazil, and in other countries (*e.g.*, Chile, Canada, South Africa, and Australia). Specific content should be emphasized in Engineering Geology disciplines in areas subjected to earthquakes. In general, teaching focuses on the following 4 main groups of activities: the first, based on access to teaching materials for each topic in the format of books, videos and lectures available in libraries and websites created for the disciplines; the second, with face-to-face activities, involving solution of practical problems related to a specific topic and pertinent to the course (civil, environmental, mining); the third, centered on field and laboratory work, and the fourth focusing on development and data analysis resulting from different types and levels of investigation and their application in specific projects of civil works, mineral exploration, and environmental problems, with both face-to-face and non-face-to-face teaching methodologies. In this period, the use of data available in databases, technical reports, and field activities has gained importance.

Engineering Geology Teaching experience in the São Carlos School of Engineering at University of São Paulo.

The teaching of Engineering Geology at EESC can be divided into three main phases:

a) First phase

Disciplines related to geological knowledge have been part of the Civil Engineering course at the São Carlos School of Engineering at the University of São Paulo (EESC-USP), since the beginning of the course, more than 70 years ago. During the first few years, the subjects dealt with geology topics for engineers, and it was only approximately 10 years later that they began to include content related to Engineering Geology. The course was called Engineering Geology, which has remained the same to date and the disciplines were taught by Professor Alfredo José Simon Bjornberg, followed by Professors Nilson Gandolfi, Antenor Braga Paraguassu, and José Eduardo Rodrigues. The group's work and experience gave rise to a set of didactic texts intended for the teaching of Engineering Geology and which were intensively used until the end of the 1990s at EESC and at other universities. The undergraduate courses totaled 200 hours in the first 40 years and, recently, around 150 hours for the Civil Engineering course. The Engineering Geology disciplines totaled more than 200 hours for the Environmental Engineering course.

b) Second phase

In 1977, the Graduate Program in Geotechnics was created, and Engineering Geology was taught in 3 to 5 different subject groups. Therefore, Engineering Geology at EESC/USP is over 50 years old.

At the graduate level, Engineering Geology, Soil Mechanics, and Rock Mechanics were taught in the context of the term Ground Engineering (Figure 1), as proposed by Morgenstern (2000), JEWG (2004), Bock et al. (2006) and JTF (2004) and considering the comments pointed out by Terzaghi (1957) and Müller-Salzburg (1980). The topics are listed in specific Tables in supplementary materials (Ribeiro et al., 2023) and were taught through different approaches, however, in a more detailed manner than those taught in the undergraduate course. They followed the fundamental triangle of Engineering Geology proposed by Bock (2006) for providing conditions for the solution of different technical and scientific points, as considered by JEWG (2004).

Engineering Geology is mandatory in the graduate program for all students at the master's degree level. The course content focuses on practical components, identifying and characterizing geological materials, laboratory tests, and use of geological and engineering geological maps, consistently exceeding 50% of the didactic activities. The topics taught up to around 2000 at both undergraduate and graduate levels were: General concepts, Engineering Geology and Geotechnics, The Earth and its divisions, Minerals, Rocks, Geological Structures, Stratigraphic rules, Earthquakes, Unconsolidated materials, Weathering, Classifications of soils, Regional and detailed geology, Geological maps, Geological materials, such as different construction materials (*e.g.*, aggregates), Engineering Geology applied in Rock Excavation/Rock

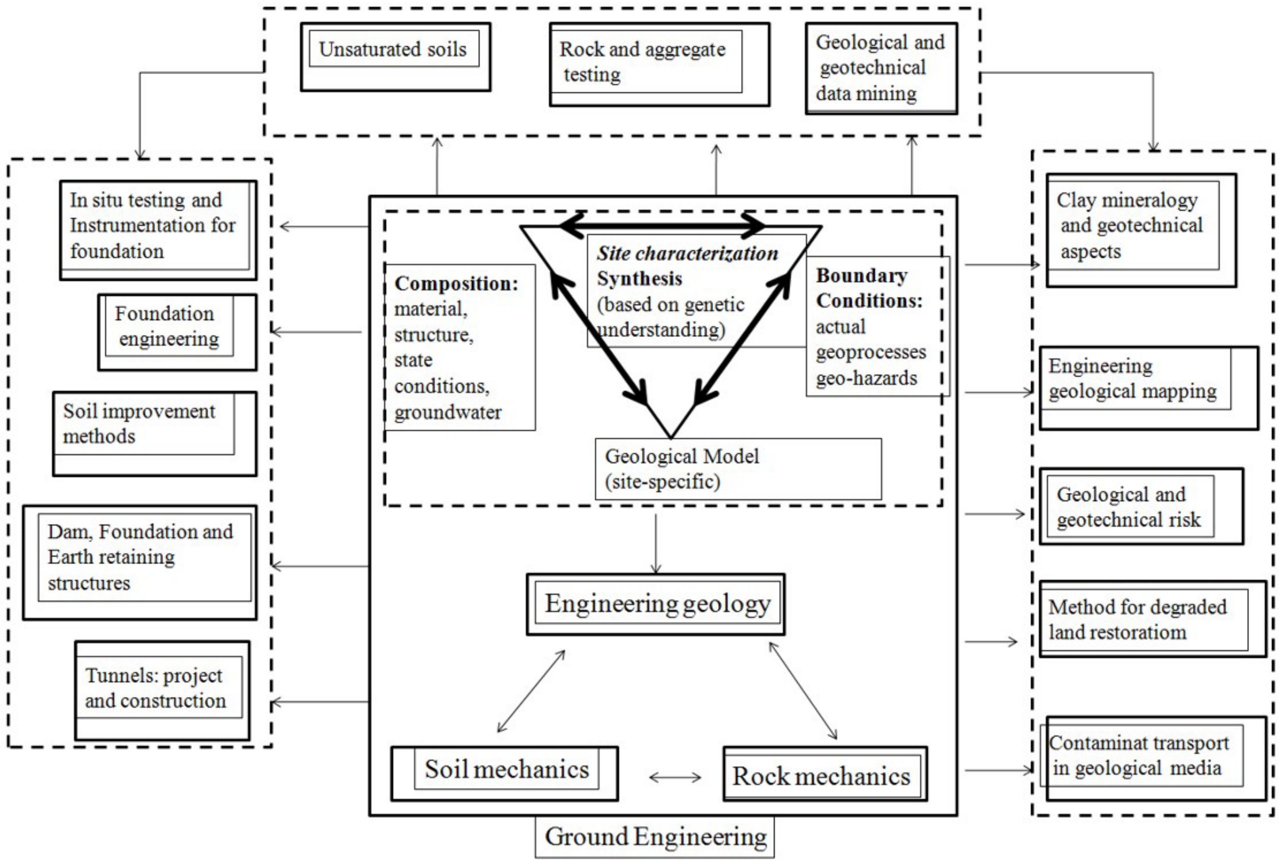

Figure 1. Flowchart with the basic disciplines offered by the Geotechnical Department at the graduate level.

blasting, Foundation, Dams, Embankments, Tunnel, Roads, Slopes, Geological and geotechnical investigation, Geological discontinuities, Rock mass classifications, and Gravitational mass movements in rock, and three field trips were programmed. More details about the topics can be found in supplementary materials (specific Table) in Ribeiro et al. (2023).

c) Third phase

From 2000 onwards, new content (subjects) has been added to the Engineering Geology disciplines at both undergraduate and graduate levels. The Environmental Engineering course was created at EESC/USP and new disciplines - totaling 7 – including topics and teaching methods were mostly related to environmental components, mainly geological media. New topics, namely, Geotechnical properties and physical and geological characteristics, Classifications of regolith profiles (saprolites and weathered rocks), Water (saturated and unsaturated zones), Models (geological and conceptual), Geological materials as different construction materials, Hydraulic Structures and Terrain models, and 3D and 4D analyses were inserted into different disciplines and the content varied according to the undergraduate course, *i.e.*, Civil or Environmental Engineering. More details about the topics can be found in supplementary materials (Ribeiro et al., 2023). It is noteworthy that those topics have been added in stages and challenges still must be overcome (*e.g.*, number of hours/classes to be inserted with due care and relevance and more practical activities and field works whereby students can be in direct contact with different engineering geological situations). Among such challenges, two, namely, financial support from universities and authorization from companies for fieldwork on highways, roads, and areas with outcrops of geological structures and geological materials with intrinsically essential characteristics for both understanding of environmental problems and engineering works must be emphasized. On the other hand, such problems are not pertinent at the graduate level due to the smaller number of students and the easier operationality to be solved in terms of costs and time.

Three points can be mentioned regarding challenges and perspectives. The first is related to the way to equip laboratories for practical classes with equipment developed with recent technology, from simple magnifiers to the most sophisticated devices for the obtaining of physical and chemical characterization parameters, as well as classrooms with computers and programs for different goals, ranging from data processing, preparation of 3D/4D models, and mathematical simulations, considering both geological and geotechnical data. The second refers to the use of data mining resources that provide access to data from different sources related to Engineering Geology pertinent to the sites investigated for different purposes. Finally, the third considers the possibility of developing artificial intelligence routines that can identify geological materials from basic physical characteristics using neural networks and estimate geotechnical properties based on databases from those characteristics. Over the last 5 years, attempts have been made towards the insertion of new topics such as Geological processes, Interaction with the works and as a source of risk, Engineering geological/geotechnical maps, Environmental problems, Slope stability assessments and monitoring in active open-cast mines, Models in Geotechnics, and Engineering geology applied to offshore areas. They are advanced in Environmental Engineering courses due to the existing disciplines, which, besides the two classic ones, include Geomorphological, Geological and Hydrogeological Constraints, Recovery of Degraded Areas, Geological, Geomorphological, and Engineering Geological Cartography, and Geographic Information Systems, in which specific topics of Engineering Geology are adopted. More details about the topics can be found in supplementary materials (Ribeiro et al., 2023).

Figure 2 shows a simplified flowchart with the subjects taught by the Geotechnical Department and by other departments of EESC-USP (Hydraulic and Sanitation, Structural Engineering, and Transportation Engineering), which have interfaces with the contents taught in the Engineering Geology disciplines. A more complete figure can be found in the supplementary materials (Ribeiro et al., 2023). The issues considered in Engineering Geology 1 (EG 1) are essential, hence, related to all the other Geotechnical disciplines and those taught in other departments. Part of the subjects considered in EG 1 is the basis for teaching topics related to interactions of EG aspects with engineering works. Discipline Engineering Geology 2 (EG 2) covers subjects more directly related to the applied disciplines of Geotechnics and those of other departments.

Figure 3 displays a simplified flowchart with the subjects of Geotechnics and other areas of knowledge of EESC-USP (Transportation Engineering and Hydraulic and Sanitation Departments and Architecture School of São Carlos - University of São Paulo), in which content interactions are taught in Environmental Engineering course disciplines. A more complete figure can be found in the supplementary materials (Ribeiro et al., 2023). Part of the topics addressed in Engineering Geology, listed in the supplementary materials, are taught in five disciplines of the Environmental Engineering course and related to four others of the Geotechnical Department, with more applied approaches. The distribution of the themes into five disciplines favors the teaching conditions, since they are distributed in

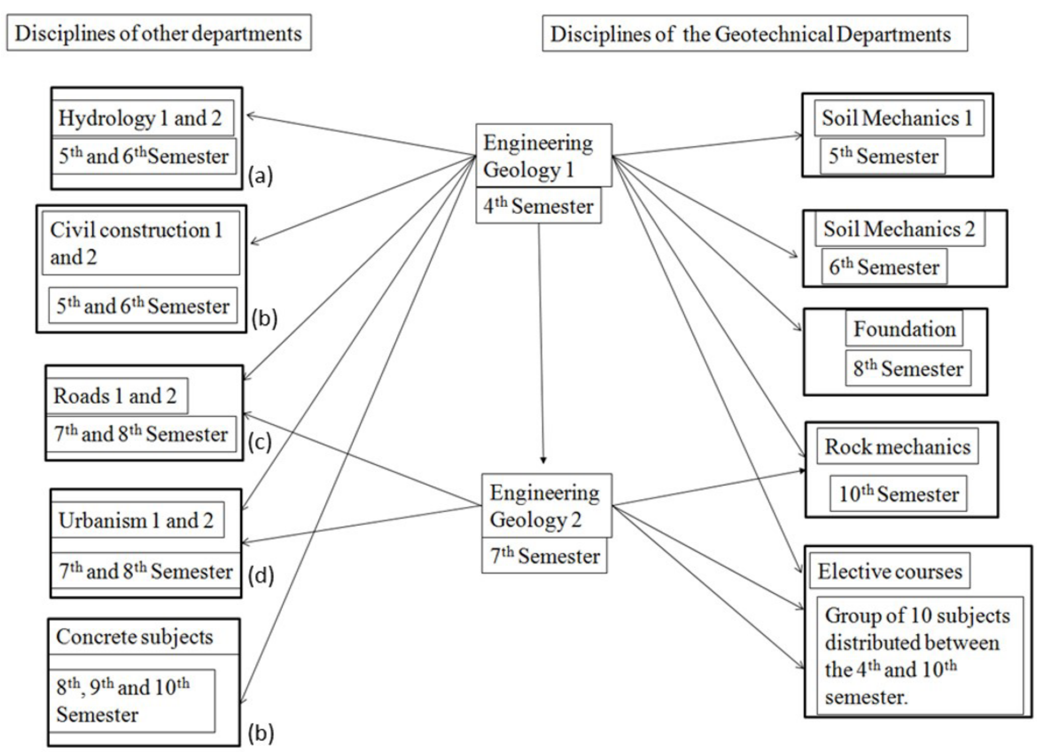

Figure 2. Relationship among the subjects of Engineering Geology and other disciplines in the Civil Engineering course of EESC-USP. Legend of the other departments: (a) Hydraulic and Sanitation, (b) Structural Engineering, (c) Transportation Engineering - Engineering School of São Carlos/University of São Paulo; (d)Architecture School of São Carlos - University of São Paulo.

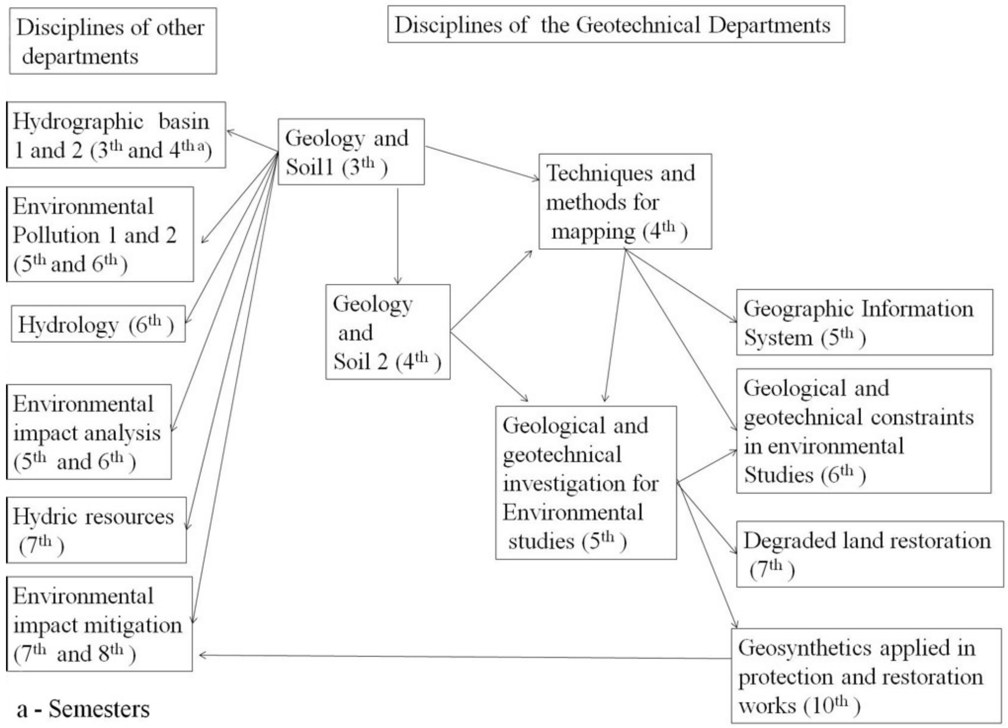

Figure 3. Relationship among the subjects of Engineering Geology and other disciplines in the Environmental Engineering course at EESC-USP. Legend: Other departments: Hydraulic and Sanitation, Structural Engineering, and Transport Engineering - Engineering School of São Carlos and Architecture School of São Carlos - University of São Paulo.

such a way one is the base for the other courses offered by the Geotechnical Department ad by other departments at EESC. The distribution of the courses from other departments between the 3rd and 8th semesters, with a certain parallelism with the five Engineering Geology disciplines, enables connecting topics among the disciplines.

5. Final considerations

Engineering Geology and its teaching have evolved with the development of areas fundamental to Geotechnics and the primary areas of knowledge (Physics, Chemistry, among others) and with the advances in technological resources that promote improvements in engineering geological investigation methods and data treatments. Moreover, the growth in the number of engineering activities, natural disasters, and environmental problems has demanded more knowledge on Engineering Geology. In general, theoretical content includes the following topics: minerals and rocks, geological structure, quaternary geomorphology, rock and rock engineering properties, groundwater, adverse geological processes and geological disasters, engineering geological problems of tunnels and underground caverns, engineering geological evaluation of special geological materials and sites, and engineering geological investigation and application, whereas practical content includes laboratory experiments, geological fieldwork, and comprehensive practices. Among them, rock and mineral recognition in the laboratory is a vital teaching link in Engineering Geology disciplines and the basis for field recognition and identification of rocks. Field engineering geology practice provides students with more direct knowledge on rocks, engineering geological conditions, engineering geological problems, among other contents. Students can understand the methods and steps of engineering geological evaluation by performing activities and improving their ability to solve practical engineering geological problems. Through comprehensive exercises, they can enhance their ability to integrate theory with practice and analyze issues comprehensively.

In Brazil, the progress of teaching Engineering Geology for Geology (which is not the objective of this text) and Engineering courses over the last 20 years has been insignificant, except for a few institutions; it is still at a very low level in most private institutions. In both public and private schools, the Geotechnical content is usually inserted into two subjects - one with the content of Geology and Soil Mechanics (elementary content) and the other with the content of foundations and earthworks. In some educational institutions with significant advances in Geotechnical education, Engineering Geology teaching has also advanced regarding both content and technological resources.

The prospects for Engineering Geology teaching are related to four general aspects. First, they concern advances in educational institutions related to course content and demands with regimental changes; second, they are related to the monitoring of the evolution of knowledge in geotechnics as a whole and interaction with soil and rock mechanics in terms of ground context; third, they refer to the way Engineering Geology will integrate technological advances of data analysis and processing in professional activities; finally, they regard the way to deal with advances in the use of actual data in studies and projects on environmental problems, estimates of dangerous events and risks, management, and responses to disasters, work in oceanic areas, and demands arising from global changes.

Knowing how professors and institutions will manage increasing subjects and contents in the curricula while maintaining the number of class hours is a challenge. The fundamental point is to consider the way didactic activities will be developed towards meeting the conditions for teaching, focusing on four large groups of resources, i.e., based on access to materials of each subject or topic in the format of books, videos, and lectures available on websites, face-to-face activities involving the solution of practical problems on a specific topic, field and laboratory works, and development and analysis of specific civil works projects, mineral exploration, and environmental problems, with both face-to-face and non-face-to-face methodologies.

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Declaration of interest

The authors declare no conflicts of interest. All co-authors have observed and affirmed the contents of the paper and there is no financial support to report.

Authors' contributions

Rogério Pinto Ribeiro: conceptualization, data curation, visualization, writing - original draft. Osni José Pejon: conceptualization, data curation, methodology, supervision, validation, writing - original draft. Lázaro Valentim Zuquette: formal analysis, funding acquisition, investigation, methodology, project administration, writing - original draft. All authors have read and agreed on the published version of the manuscript.

Data availability

All data produced or examined in the course of the current study are included in this article.

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Appendix 1. Basic references for the understanding of Engineering Geology advances.

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