The use of a video and a small-scale model for rain-induced landslides in geotechnical engineering education

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Abstract: Small-scale physical models of geotechnical problems are thought-provoking didactic tools that motivate students by arousing their curiosity and facilitating the understanding of physical phenomena and theoretical concepts. This work presents the development of an educational video about slope stability failures and its contributing factors. It shows several small-scale models built in a glass wall tank measuring 150 x 50 x 10 cm. Layers of fine gravel were placed on a sloping surface of polystyrene to represent a slope with a layer of residual soil on rock. Toy houses and cars were used to represent anthropogenic agents, and water with dye represents the groundwater flow. Each model depicts a different scenario of shallow slope failure. The objective of the video is to show that most slope failures in urban areas result from natural and anthropogenic factors. Several influence factors are shown: porewater level rise, excavation, surcharge application, and solid urban waste deposition. The 6-minute video has had more than 130,000 views on YouTube. Thanks to its simple and concise language, the video is shown in basic education and science museum, as well as in graduate and undergraduate courses. A questionnaire survey was carried out with undergraduate students to assess how helpful the video was for the learning process. This article explains the construction of the model, the video script, and the strategies for its use, as well as its reception. It was found that the video promoted motivational and learning benefits of providing context, establishing relevance, and teaching inductively.

Keywords: Landslides; Physical modeling; Disaster education; Slope stability; Educational video

1. Introduction

Landslides are a frequent natural hazard and a major threat to humans and the environment worldwide (UNISDR, 2017). The rate of rain-induced landslide disasters has significantly increased in quantity and impact magnitude over time. However, being greatly underestimated, many were incorrectly attributed to other associated events such as floods, storms or earthquakes (Petley, 2012; Hernández-Moreno & Alcántara-Ayala 2017). Despite the fact that the numbers are underestimated, the International Disaster Database (EM-DAT, 2023), which uses the criterion of a minimum of ten fatalities for an event to be included in the database, recorded a total of 371 landslides causing 17,159 fatalities and about 4.8 million affected people during the period 2002 – 2022 worldwide. It is also important to mention that the participation of human activity as triggering factors of landslides, in particular in relation to construction and hill cutting, is increasing (Froude & Petley, 2018).

Based on the Brazilian Atlas of disasters (Brasil, 2023), 1,246 landslide disasters were officially registered in Brazil between 2001 and 2021, involving 604 fatalities and 4.2 million affected people. Similarly to what occurs on a global level, these quantities are, however, heavily understated. The association of data from the 2010 Demographic Census with those deriving from mappings carried out in risk areas in 872 Brazilian municipalities monitored by the National Center for Natural Disaster Monitoring and Alerts in 2018 allowed estimating that the population living in landslide and flooding risk areas, in these municipalities, back in 2010, comprised approximately 8.3 million inhabitants (IBGE, 2018). Landslide disasters in Brazil reveal a form of social organization which results in rapid and disorganized settlement of landslide-prone areas by poor populations (Da-Silva-Rosa et al., 2015). According to Macedo & Sandre (2022), the ten most affected Brazilian cities between 1988 and 2022 comprised 63% of the deaths in Brazil. These cities have great importance for their states and metropolitan areas, and attract internal migration that increases the pressure for occupation of landslide-prone areas.

The role of the university is highlighted in the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2015), which is the main international tool for disaster risk reduction. One of its four main priorities is a clear understanding of the disaster risk by means of improving the knowledge in every educational level to make society more resilient. Oliveira (2009) assessed the future of Geo-Engineering Education, and highlighted the importance of environmental issues in geotechnics since they are associated to problems that may cause great harm to society, like natural hazards from inadequate land use, and landslides.

Given the current prevision landslide disasters, there is a growing demand for professionals prepared for the planning and implementation of risk reduction actions, according to the Sendai Framework strategies. The geotechnical engineer plays an important role in this process since he or she is the professional who, along with other geoscience professionals, such as geologists and geomorphologists, seeks to understand and model the different types of landslide phenomena and their various conditioning factors to propose the most suited mitigation measures for local realities. This issue, however, is not limited to the landslide mechanism. Rather, it involves the social system that can influence and be affected by it, at the same time. Malamud & Petley (2009) highlight that most disasters occur because of complex interactions involving hazardous processes and social systems, and the only logical way to address disaster risk reduction is to consider both elements simultaneously, which means an interdisciplinary approach.

In this context, geotechnical courses are needed to address the issue of slope stability considering the local reality of the social system using pedagogical resources that facilitate this understanding by students. However, it has been observed that normally geotechnical engineers trained in civil engineering courses, even with master's and doctoral degrees, become over-reliant on theories and their equations, being far from real field conditions, which in the case of landslide disasters have a major social component. Small-scale models may play an important role in improving the learning and teaching conditions. Black et al. (2018) advocate for greater adoption of experiment-based observation/demonstration to be embedded within the geotechnical undergraduate curriculum to enrich the student learning experience. Becker et al. (2018) used small scale models to assist students in understanding flow theory and applications. This work aims to discuss the conception of a didactic video that uses a reduced model to address the issue of slope stability, presenting the main anthropic aspects that may contribute to landslides, as well as their consequences. The work also presents how the video was used in different spaces of education and the evaluation by an undergraduate class in civil engineering at the Federal University of Rio de Janeiro.

2. Materials and methods

2.1. The basis of the design of the video on slope stability

Considering the demands mentioned above, the slope stability video was conceived by combining two basic principles, the observational method, and the real-world approach.

Engineering schools and professors have been told to adopt some directions to diminish the deficiencies in engineering education. Among these directions are teaching more about "real-world" engineering design and operations and producing graduates who are conversant with the connections between technology and society (Felder et al., 2000).

In a study on effective learning experiences that best support the development of expert professional practice in engineering courses, Litzinger et al. (2011) mentioned using context-rich, multifaceted problems as an approach to help students develop more sophisticated problem-solving skills than those built when solving typical textbook problems. This kind of approach is a strategy to link abstract content to realistic problems, which also increases the students' motivation.

The material used in engineering courses by the instructor can be categorized as concrete (facts, observations, experimental data, applications) or abstract (concepts, theories, mathematical formulas, and models). Although the use of these materials varies from one course to another, the balance between these two categories has shifted toward abstraction in recent decades. In this context, Felder et al. (2000) pointed out the challenge to provide sufficient concrete material to have a better balance. According to the authors, introducing new abstract information grounded in the student's existing knowledge and experience provided by concrete content helps to encode it in the students' long-term memories. Also, the concrete content should be tied to "real-world" situations to increase motivation.

Kusakabe (2022), in his work on development and challenges of physical modeling in geotechnical engineering, reminded the proverb “To see is to believe” to highlight that observation is the starting point for modern science. Observation should not be limited to engineering design activities. Rather, it should be extended to any process that requires consideration on material behavior and its consequences. In fact, some concrete materials, such as reduced models, have been used to represent various physical processes in geo-engineering education to improve student learning (e.g. Atkinson, 2007; Jaksa, 2008; Herle & Gesellmann, 2008; Seo & Yi, 2023).

In this regard, a video of a small-scale physical model interspersed with animation was conceived to be used in undergraduate courses of Civil Engineering to explain landslides. This video is a kind of concrete material to introduce the issue, considering the reality of the landslide disasters in human-occupied slopes, as described in the preceding section. The video was designed to be used as a thought-provoking didactic tool.

Simple language was used and complex theoretical explanations were avoided to make the video suitable for the layman.

2.2. The video script

The video was conceived to address the following key points: to give a context of landslide disasters in Brazil; to show the building of the small-scale experiment; to conduct the experiment while addressing the natural and anthropic triggering factors; to address the impacts of landslides.

Shallow landslides (Hungr et al., 2014) are some of the most widespread natural hazards worldwide (UNISDR, 2017). Shallow translational landslide was the type of mass movement chosen to be simulated as it is the most frequent type observed in Brazil, and usually causing great harm to society (e.g., Wolle & Hachich, 1989; Lacerda, 2007; Coelho-Netto et al., 2007; Avelar et al., 2011). Some human activities usually found in areas of disorganized land use (e.g., cutting and filling to build houses or roads, solid waste dumping deforestation, and inadequate water supply, sewage and drainage systems) increase the landslides hazard (Mendonca & Guerra, 1997; Michoud et al. 2011). Therefore, some of those were represented in the model. Table 1 shows the video script.

Table 1. Script of video available on YouTube (https://www.youtube.com/watch?v=K9i3JyXocgI).

Speech	Images (video time)
Part 1: Contextualization of landslide disasters in Brazil (0:27-1:44)	
Narrator: The objective of this video is to explain why landslides occur on the slopes, and to show how human occupation can influence these disasters. The problem occurs in several regions of Brazil, especially in the rainy season, and is repeated every year, causing loss of life, social and psychological damage. In the last 3 years, just over a thousand people died in landslides in several cities in the state of Rio de Janeiro. Much larger numbers of people, including children, the elderly and the sick, were displaced or made homeless. Added to this is the physical damage caused by the destruction of homes, roads and water and sewage networks. The poor who occupy inappropriate areas in a disorderly fashion are the ones who suffer the most from this.To understand the causes of these disasters, it is important to analyze the slope's subsoil. One of the most common types of landslides occurs where there is a thin layer of residual soil onto the rock. The thickness of the soil layers below the surface is of a few meters. Below the soil there is rock.	Images of landslides, newspaper stories etc. (0:27-1:18)
Narrator: When it rains, the water penetrates the ground through the soil layer until it reaches the rock, when it changes direction and flows down the slope. If the rain continues, the soil is saturated and the water causes a force that drags the soil down the slope.	Animation: A slope profile, showing a thin soil layer is shown. Blue arrows indicate the downward movement of the rain until it reaches the rock. Then the arrows change direction (parallel to the rock top), and the water level rises within the soil. The drawing shows a wet region within the soil and blue downward arrows parallel to the terrain. (1:19-1:44)
Part 2: building the small-scale experiment of landslides (1:45-2:37)	
Narrator: This model was created to represent a slope. The glass wall allows you to visualize what happens. An inclined plane made of polystyrene represents the rock. The soil is placed on top of it. A tank system with colored water and an electric pump represent the entry of rainwater into the land.	Model: footage of the model assembly.
Part 3: conducting the experiment addressing the natural factors (2:37-3:32)	
Narrator: The water level rises and increases the pore pressure in the terrain, but the strength of the soil is still enough to prevent a landslide.	Model: Steady water flow scenes in the model. (2:37-2:56)
Narrator: However, if the rain continues to soak the soil, the water level will rise until the strength of the soil is overcome. At this point, the landslide occurs.	Model: Scenes of water level rising and slope failure in the model. (2:56-3:14)

Narrator: As we can see in this video, the soil slides on the rock and hits everything in front of it with great energy.	Model: Scenes of the slide in slow motion. (3:14-3:32)
Part 4: conducting the experiment addressing the anthropogenic factors	
4.a - cut and fill in a slope (3:32-5:02)	
Narrator: A landslide can happen more easily if the slope is steeper. How does this happen? It is common to make excavations in the ground to have a level where a house or a street can be built. This makes the back slope steeper and easier to slide off.	Animation: step-by-step execution of two excavations on a slope, resulting in two plateaus and the “construction” of a toy house on one plateau and a toy road on the other. Then two landslides hit the house and the road. Model: show the failure of the small-scale model caused by the excavation procedure (no flow). (3:32-4:37)
Narrator: an embankment fill may be placed on the slope to make room for construction of houses or roads. If this construction is not performed properly, a slide can be triggered by it.	Animation: shows the embankment image that looks stable (section equal to the end of the excavation animation).
Narrator: Despite its “safe” appearance, the embankment fill constructed without care saturates during heavy rains, loses strength and slides.	Animation: shows the slide hitting the houses. (4:37-5:02)
4.b - solid waste dumped on the land (5:02-5:12)	
Narrator: It's even worse when one dumps rubble and solid waste on the slope.	Animation: show an accumulation of solid waste on the slope.
Narrator: This material may be weak, and slide easily when it rains.	Animation: show the slide of solid waste and debris down the slope reaching the house below.
Part 5: Final Considerations (5:12-6:12)	
Narrator: The objective of this video was to explain how and why landslides occur on the slopes, and show how the occupation can influence the occurrence of disasters. We hope you have understood why landslides occur and which are the actions that should be avoided to improve the safety of the slopes.	Collection of images of slopes and slope failures (5:12-5:38) Credits (5:38-6:12)

2.3. Construction of the small-scale model

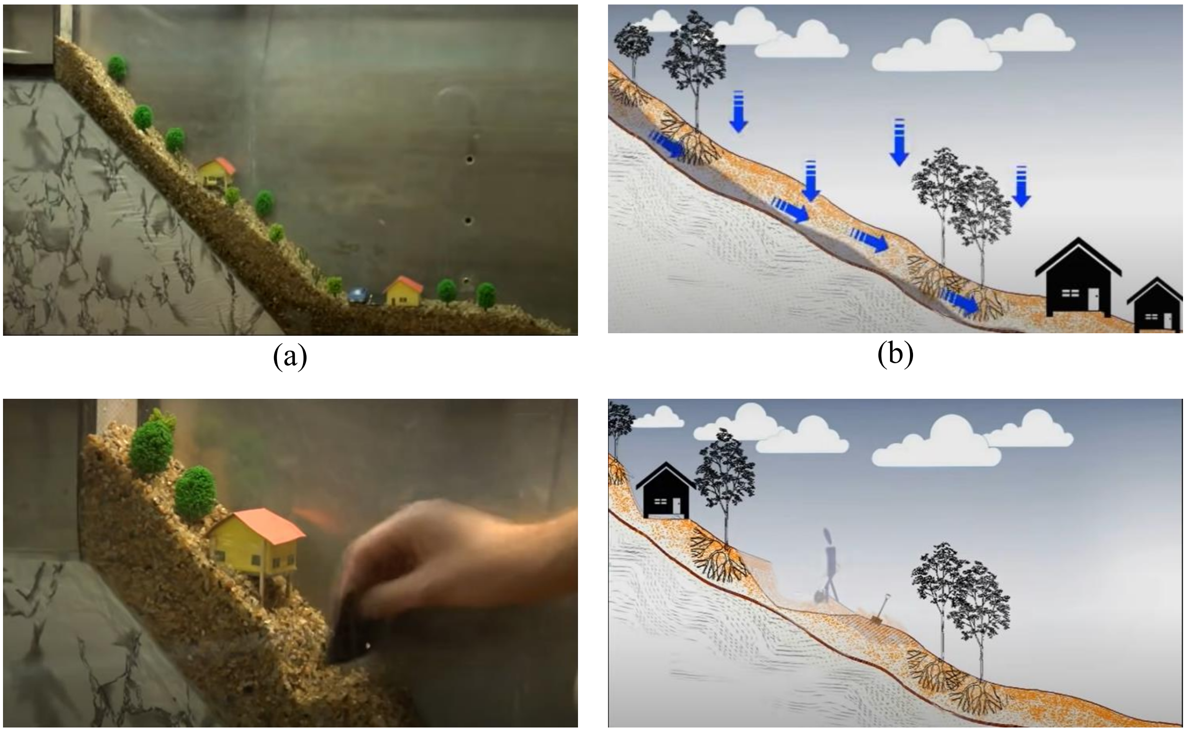
For the construction of the small-scale model, a tank of the Soil Mechanics Laboratory of the Polytechnic School of the Federal University of Rio de Janeiro was used. This tank is used for modeling water flow problems. It is made of a steel box 1.5 m wide, 1.0 m high and 0.1 m thick (Figure 1). A glass front wall and the insertion of dye in the water allow the observation of the flow lines. Below the tank, there is a water reservoir and an electric pump that may be used to establish a continuous flow in the model. An inclined plane of painted Polystyrene was inserted inside the tank to represent a sloping rock (Figure 1), on which shallow landslides occur. Fine gravel was placed on the inclined plane to represent a soil layer. Toy objects were used to represent houses, trees, roads and vehicles. Figure 1 shows some of the assemblies.

Figure 2 shows the images of the water level rising and the excavation (a, c, respectively), and the corresponding animations (b, d, respectively).

(a) (b)

(c)

Figure 1. Steel tank for flow models: (a) view of the tank and, below, the water reservoir and the electric pump; (b) detail of the glass wall and the Polystyrene inclined plane that simulates the rock; (c) slope and toy objects.



(a) (b)

(c) (d)

Figure 2. Still images of the video: (a) dyed water level flowing in the soil layer; (b) animation representing the rain infiltration and the rise of the water level; (c) excavation in the slope; and (d) animation representing the slope excavation.

3. Use of the video, assessment, and analysis

The video has a total playing time of 6min and 15s and is available on YouTube (https://www.youtube.com/watch?v=K9i3JyXocgI).

The video has been shown to undergraduate students in two disciplines (“Soil Mechanics” and “Slope Stability”).

Slope Stability is taught in the last year of the Civil Engineering course. The video is shown to the students just before they learn to deduce the Factor of Safety of an infinite slope to help them visualize the translational failure, the flow pattern caused by the rain, its detrimental effect on the stability, and the human influence. The video also has a motivational effect, as will be shown later. During the showing, the professor usually pauses the video to emphasize the position of the water level and the soil movement. Sometimes the video is shown again after the theoretical class because it allows more discussions.

In the Soil Mechanics classes, the video is shown after a theoretical class to illustrate the effect of the pore pressure in the shear strength. The video is paused just before the water level rises to emphasize that the slope failure is caused by the pore pressure increase.

In each case, some time is allowed for the students to discuss the video.

The professor observes the reactions of the students during the exhibition of the video. In the opinion of the professor, the students like the video, and seem attentive during viewing. Moreover, the video seems to enhance their learning process, and they are more prone to discuss the subject after watching the video.

To assess more precisely the effect of the video as a didactic resource, two questionnaires were applied to 44 students, one before and the other after the exhibition of the video. The video was exhibited after a theoretical class about the safety factor of the slope, in 2022. The students were asked what part of the video they liked the most. They gave several different answers, but the small-scale model was the most preferred (45% of the students). Unlike most classes, in this experiment, the video was shown after the theoretical class instead of before. However, when asked to comment on the effect of the video on the lecture, several students asked that the video be shown before the lecture.

The length of the video (6’) was considered adequate by all students, and helped increase the interest of the vast majority in the subject. Also, most students admitted paying more attention to the video than to the theoretical class (Figure 3).

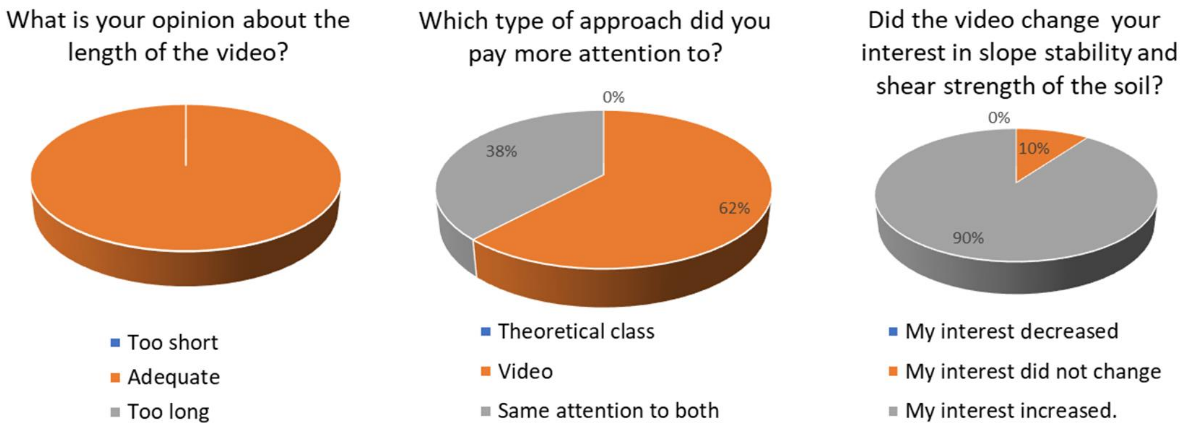


Figure 3. Opinions of the students about the video.

Two questions were designed to assess if the students had really learned the topic, and the effect of the video. The students were asked if the safety factor of a slope could be different if it were under human occupation (Figure 4), and if they had understood the failure mechanism of an infinite slope due to rain (Figure 5). It is clear that the video helped the learning process in both cases.

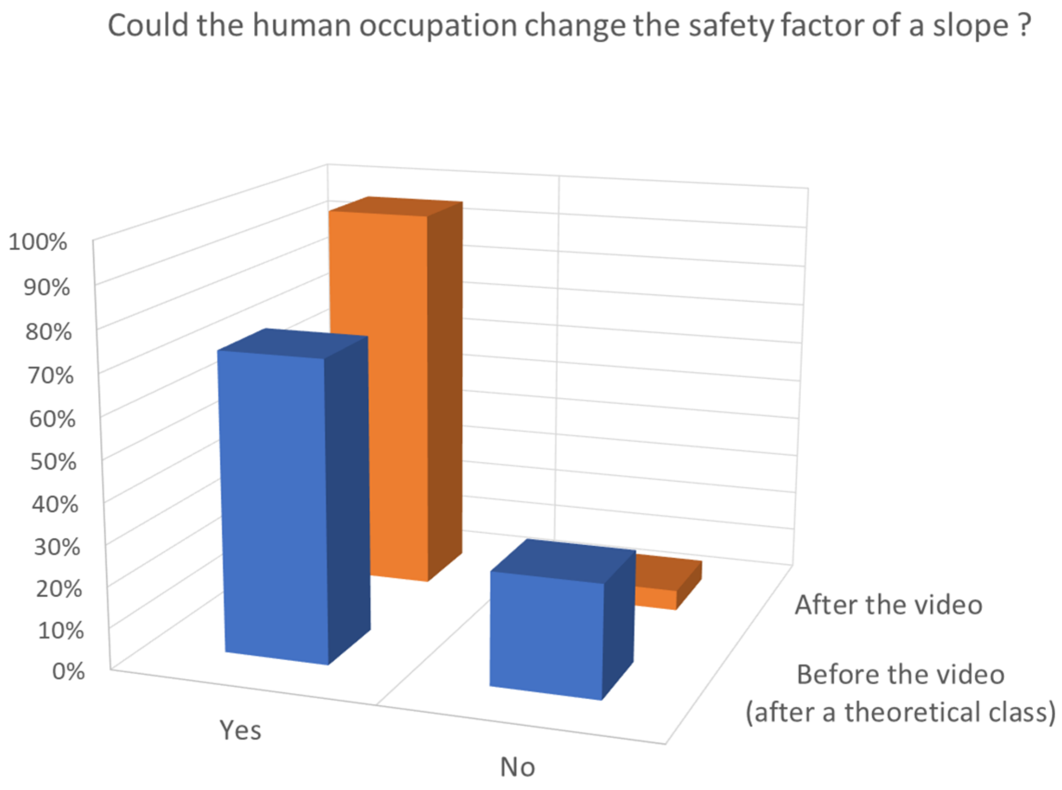


Figure 4. Students' understanding of the influence of the human occupation in the slope stability (before and after the video).

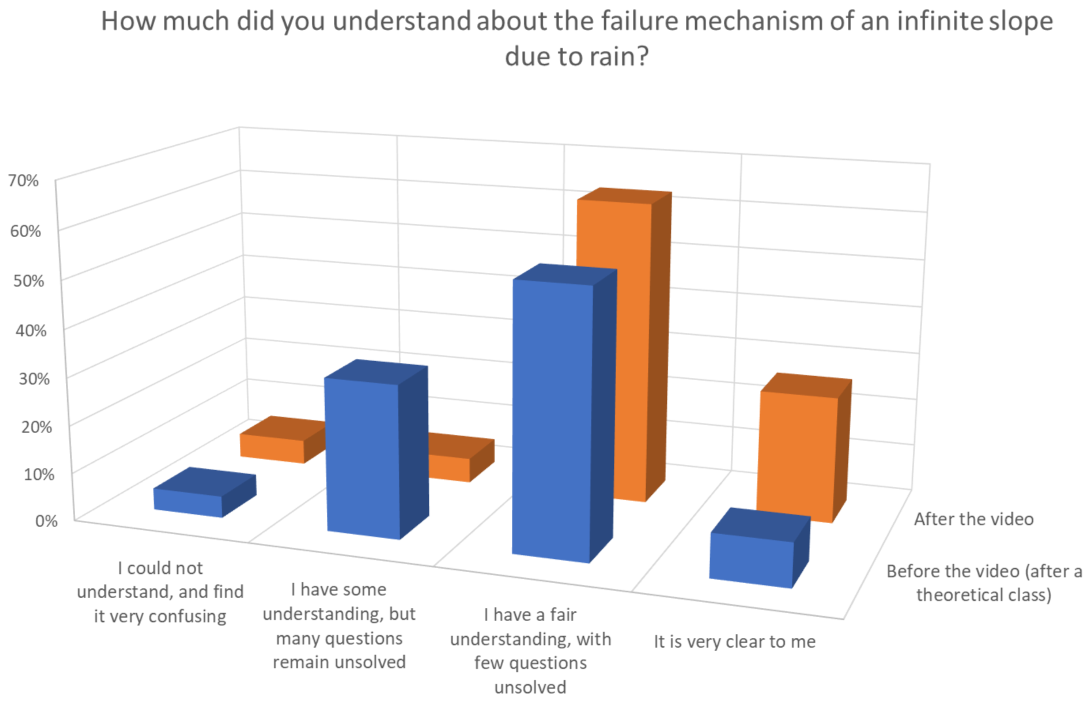


Figure 5. Students' understanding of the mechanism of a translational failure due to rain (before and after the video).

Due to its simple language, and lack of mathematical equations, the video has also been used in other formal educational structures, such as elementary schools (Mendonça & Valois, 2017), and in non-formal education, such as science museums (Mendonça et al., 2019). The simplicity of the approach and the high relevance of the theme have made the video attract a significant audience on YouTube, reaching more than 130,000 views.

4. Conclusions

The video-model tool presented in this work sought not only to improve the teaching-learning process, but also to bring the slope stability theme closer to society, contributing for geo-engineering students to gain skills to tackle more realistic problems of landslide disasters.

The use of the referred video in slope stability and soil mechanics courses meets the convergent demands of interdisciplinary approach of disasters and the consideration of real-world to facilitate the learning process. Based on Felder et al. (2000), this kind of approach that addresses more complex and broad problems helps the students to acquire skills needed to tackle challenging multidisciplinary problems that require critical judgment and creativity.

The assessment of using the video indicated that the video promoted motivational and learning benefits of providing context, establishing relevance, and teaching inductively. It is best to exhibit the video before the theoretical classes.

The video proved very useful as a didactic tool for landslide disaster prevention in several educational environments, including non formal educational spaces like science museums.

Moreover, the development of other videos using reduced models of different geotechnical problems is intended since the video usage as a pedagogical tool in the geotechnical engineering course of the Federal University of Rio de Janeiro has showed positive results. Interaction with society is also desirable, whenever possible.

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Declaration of interest

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

Authors' contributions

Marcos Barreto de Mendonça: Conceptualization, Methodology, Project administration, Writing – original draft and review.

Leonardo De Bona Becker: Investigation, Methodology, Data Curation, Writing – review & editing.

Data availability

The video is available on YouTube, https://www.youtube.com/watch?v=K9i3JyXocgI.

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

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