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Learning in an Interactive Simulation Tool against Landslide Risks: The Role of Amount and Availability of Experiential Feedback

Pratik Chaturvedi[1, 2], **Akshit Arora**[1, 3], **and Varun Dutt**[1]

[1]Applied Cognitive Science Laboratory, Indian Institute of Technology, Mandi- 175005, India

[2]Defence Terrain Research Laboratory, Defence Research and Development Organization, Delhi -110054, India

[3]Computer Science and Engineering Department, Thapar University, Patiala - 147004, India

Correspondence to: Pratik Chaturvedi (prateek@dtrl.drdo.in)

Abstract. To investigate how differing amounts of experiential feedback and feedback's availability in an interactive simulation tool influences people's decision-making against landslide risks. Feedback via simulation tools is likely to help people improve their decisions against disasters; however, currently little is known on how differing amounts of experiential feedback and feedback's availability in simulation tools influences people's decisions against landslides. We tested the influence of differing amounts of experiential feedback and feedback's availability on people's decisions against landslide risks in an Interactive Landslide Simulation (ILS) tool. In an experiment, in high-damage conditions, the probabilities of damages to life and property due to landslides were 10-times higher than those in the low-damage conditions. In feedback-present condition, experiential feedback was provided in numeric, text, and graphical formats in ILS. In feedback-absent conditions, the probabilities of damages were described; however, there was no experiential feedback present. Investments were greater in conditions where experiential feedback was present and damages were high compared to conditions where experiential feedback was absent and damages were low. Furthermore, only high-damage feedback produced learning in ILS. Experience gained in ILS enables people to improve their decision-making against landslide risks. Simulation tools seem appropriate for landslide risk communication and for performing what-if analyses.

1 Introduction

Landslides cause massive damages to life and property worldwide (Chaturvedi and Dutt, 2015; Margottini et al., 2011). Knowledge about causes-and-consequences of landslides and awareness about landslide disaster mitigation are likely to help people take good mitigation actions that prevent landslides from occurring (Becker et al., 2013; Osuret et al., 2016; Webb and Ronan, 2014). However, to educate people about cause-and-effect relationships concerning landslides, effective landslide risk communication systems (RCSs) are needed (Glade et al., 2005). To be effective, these RCSs should possess five main components (Rogers and Tsirkunov, 2011): monitoring; analyzing; risk communication; warning dissemination; and, capacity building.

Among these components, prior research has focused on monitoring and analyzing the occurrence of landslide events (Dai et al., 2002; Montrasio et al., 2011). For example, there exists various statistical and process-based models for predicting landslides (Dai et al., 2002; Montrasio et al., 2011). To be effective, however, landslide

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RCSs need not only be based upon sound scientific models; but, they also need to consider human factors, i.e., the knowledge and understanding of people residing in landslide-prone areas (Meissen and Voisard, 2008). Thus, there is an urgent need to focus on the development, evaluation, and improvement of risk communication, warning dissemination, and capacity building measures in RCSs.

Improvements in risk communication strategies are likely to help people understand the cause-and-effect processes concerning landslides and help them improve their decision-making against these natural disasters (Grasso and Singh, 2009). However, surveys conducted among communities in landslide-prone areas (including those in northern India) have shown a lack of awareness and understanding among people about landslide risks (Chaturvedi and Dutt, 2015; Oven, 2009; Wanasolo, 2012). In a survey conducted in Mandi, India, Chaturvedi and Dutt (2015) found that 60% of people surveyed were not able to answer questions on landslide susceptibilities maps, which were prepared by experts. Also, Chaturvedi and Dutt (2015) found that a sizeable population reported landslide as “an act of God” (39%) and attributed activities like “shifting of temple” as causing landslides (17%), which shows numerous misconceptions about landslides among people in landslide-prone areas. Overall, research is needed that improves public understanding and awareness about landslides in affected areas.

Promising recent research has shown that experiential feedback in simulation tools likely helps improve public understanding about dynamics of physical systems (Dutt and Gonzalez, 2010; 2011; 2012; Fischer, 2008). Dutt and Gonzalez (2012) developed a Dynamic Climate Change Simulator (DCCS) tool, which was based upon a more generic stock-and-flow task (Gonzalez and Dutt, 2011a). The authors provided frequent feedback on cause-and-effect relationships concerning Earth’s climate in DCCS and this experiential feedback helped people reduce their climate misconceptions compared to a no-DCCS intervention. Although prior literature has investigated the role of frequency of feedback about inputs and outputs in physical systems, yet little is known on how differing amounts of experiential feedback (i.e., differing probabilities of damages due to landslides) influences people’s decisions over time. Also, little is known on how experiential feedback’s availability (presence or absence) influences people’s decisions.

The main goal of this paper is to evaluate how differing amounts of experiential feedback and feedback’s availability influences people’s mitigation decisions. It is important to understand how differing experiential feedback in terms of differing probabilities of damages influences people’s mitigation decisions. That is because the experience of landslide consequences could range from no damages to large damages involving several injuries, infrastructure damages, and deaths. Thus, some people may experience severe damages and consider landslides to be a serious problem requiring immediate actions; whereas, other people may experience no damages and consider landslides to be a trivial problem requiring very little attention.

Interactive simulation tools provide a way of evaluating how experiential feedback influences people’s decisions (Chaturvedi et al., 2016). Chaturvedi et al. (2016) proposed a computer-simulation tool, called the Interactive Landslide Simulator (ILS). The ILS tool is based upon a landslide model that considers the influence of both human factors and physical factors on landslide dynamics. Thus, in ILS, both physical factors (e.g., spatial geology and rainfall) and human factors (e.g., monetary contributions to mitigate landslides) influence the probability of catastrophic landslides.

In a preliminary investigation, Chaturvedi et al. (2016) conducted an experiment with human participants to gauge the effectiveness of the ILS tool. The probability of damage due to landslides was varied at two levels in ILS: low probability and high probability. The high probability was set about 10-times higher compared to the low probability. People were asked to make monetary investment decisions, where the monetary payment would be used for mitigating landslides (e.g., by building a retaining wall or by planting crops with long roots in landslide prone areas). People's investments were significantly greater when the damage probability was high compared to when this probability was low. However, Chaturvedi et al. (2016) did not fully evaluate the effectiveness of experiential feedback of damages in ILS tool against control conditions where this experiential feedback was not present. Also, Chaturvedi et al. (2016) did not investigate people's investment decisions over time in ILS, where overtime decisions are indicative of learning of landslide dynamics in the tool.

Prior literature on learning from experiential feedback (Baumeister et al., 2007; Dutt and Gonzalez, 2012; Finucane et al., 2000; Knutty, 2005; Reis and Judd, 2013; Wagner, 2007) suggests that increasing the amount of damage feedback (i.e., increasing the probabilities of landslide damages) in simulation tools would likely increase people's mitigation decisions. That is because a high probability of landslide damages will make people suffer monetary losses and people would tend to minimize these losses by increasing their mitigation actions. It is also expected that the presence of experiential feedback about damages in simulation tools is likely to increase people's landslide-mitigation actions (Dutt and Gonzalez, 2010; 2011; 2012). That is because the experiential feedback about damages will likely enable people to make decisions and see the consequences of their decisions; however, the absence of this feedback will not allow people to observe the consequences of their decisions once these decisions have been made (Dutt and Gonzalez, 2012).

In this paper, we evaluate the influence of differing amounts of experiential feedback about landslide-related damages and the experiential feedback's availability in the ILS tool. More specifically, we test whether people increase their mitigation actions in the presence of experiential damage feedback compared to in the absence of this feedback. In addition, we evaluate how different probabilities of damages influence people's mitigation actions in the ILS tool. Furthermore, we also analyze people's mitigation actions over time across different conditions.

In what follows, first, we detail a computational model on landslide risks that considers the role of both human factors and physical factors. Next, we detail the working of the ILS tool, i.e., based on the landslide model. Furthermore, we use the ILS tool in an experiment to evaluate the influence of differing amounts of experiential feedback and feedback's availability on people's decisions. Finally, we close this paper by discussing our results and detailing the benefits of using tools like ILS for communicating landslide risks in the real world.

2 Computational model of landslide risk

Chaturvedi et al. (2016) proposed a computational model for simulating landslide risks that was based upon the integration of human and physical factors (see Figure 1). Here, we briefly detail this model and use it in the ILS tool for our experiment (reported ahead). As seen in Figure 1, the probability of landslides due to human factors is adapted from a model suggested by Hasson et al. (2010) (see box 1.1 in Figure 1). In Hasson et al. (2010)'s model,

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the probability of a disaster (e.g., landslide) due to human factors is a function of the cumulative monetary contributions made by participants to avert the disaster from the total endowment available to participants.

Furthermore, in the landslide model, the probability of landslides due to physical factors (see box 1.2) is a function of the prevailing rainfall conditions and the nature of geology in the area (Mathew et al., 2013). As shown in Figure 1, the ILS model focuses on calculation of total probability of landslide (due to physical and human factors) (box 1.3). This total probability of landslide is calculated as a weighted sum of probability of landslide due to physical factors and probability of landslide due to human factors. Furthermore, the model simulates different types of damages caused by landslides and their effects on people's earnings (box 1.4).

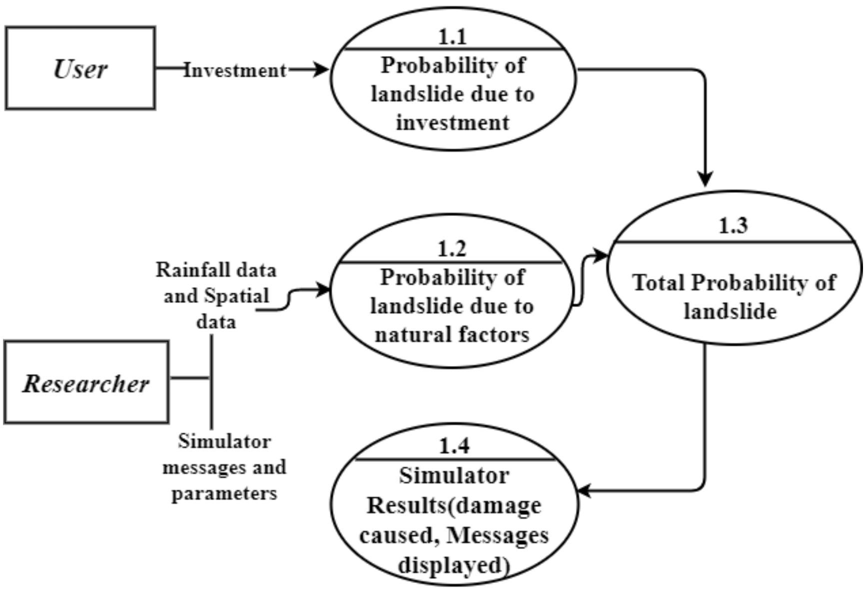

Figure 1. Probabilistic model of the Interactive Landslide Simulator tool. Figure adapted from Chaturvedi et al. (2016).

2.1 Total probability of landslides

As described by Chaturvedi et al. (2016), the total probability of landslides is a function of landslide probabilities due to human factors and physical factors. This total probability of landslides can be represented as the following:

$$P(T) = \left(W * P\ (I) + \ (1 - W) * P\ (E)\right) \quad (1)$$

Where W is the weight factor, which is between [0, 1]. The total probability formula involves calculation of two probabilities, probability of landslide due to human investments (*P(I)*) and probability of landslide due to physical factors (*P(E)*). These probabilities have been defined below. According to Equation 1, the total probability of landslides will change based upon both human decisions and environmental factors over time.

2.1.1 Probability of landslide due to human investments (*P(I)*)

As suggested by Chaturvedi et al. (2016), this probability is calculated using the probability model suggested by Hasson et al. (2010). The probability of landslide due to human investments is:

$$P(I) = 1 - \frac{M * \sum_{i=1}^{n} x_i}{n * B} \qquad (2)$$

Where,

B = Budget available towards addressing landslides for a day (if a person earns an income or salary, then B is the same as this income or salary earned in a day).

n = Number of days.

x_i = Investments made by a person for each day *i* to mitigate landslides; $x_i \leq$ B.

M = Return to Mitigation, which is a free parameter and captures the lower bound probability of *P(I)*, i.e., *P (I) = 1-M* when a person puts her entire budget B into landslide mitigation ($\sum_{i=1}^{n} x_i = n * B$).

People's monetary investments (x_i) are for mitigation measures like building retaining walls or planting long root crops.

2.1.2 Probability of landslide due to physical factors (*P(E)*)

Some of the physical factors impacting landslides include rainfall, soil type, and slope profile (Chaturvedi et al., 2016; Dai et al., 2002). These can be categorized into two parts:

1. Probability of landslide due to rainfall (*P(R)*)
2. Probability of landslide due to soil type and slope profile (spatial probability, *P(S)*)

Given *P(R)* and *P(S)*, the probability of landslide due to physical factors, *P(E)* is defined as:

$$P(E) = P(R) * P(S) \qquad (3)$$

The methodology adopted here comprises of two steps. In the first step, *P(R)* is calculated based upon a logistic-regression model (Mathew et al., 2013) as follows:

$$P(R) = \frac{1}{1+e^{-z}} \qquad (4a)$$

And,

$$z = -3.817 + (DR) * 0.077 + (3DCR) * 0.058 + (30DAR) * 0.009$$

$$z: (-\infty, +\infty) \qquad (4b)$$

Where, the DR, $3DCR$, and $30DAR$ is the daily rainfall, the 3-day cumulative rainfall, and the 30-day antecedent rainfall. These parameters are determined for a specific geographical location using the historical rainfall data. Once these parameters are determined, equation 4a and 4b help determine the probability of landslide due to rainfall, $P(R)$. In the ILS tool reported ahead, $P(R)$ is shown as the probability of landslides due to rainfall in a certain trial.

The second step is to evaluate spatial probability of landslides, *P(S)*. The determination of *P(S)* is done from Landslide Susceptibility Zonation (LSZ) map of the area (Anbalagan, 1992; Chaturvedi et al., 2016; Clerici et al., 2002), which are based on geomorphological factors in the study area (Mandi area in northern India). The spatial probability is computed based upon the Total Estimated Hazard (THED) rating of different locations on a Landslide Hazard Map and their surface area of coverage (the maximum possible value of THED is 11.0). For example, if a THED of 3.5 has a 20% coverage area on LSZ, then the spatial probability is less than equal to 0.32 (= 3.5/11) with a 20% chance. Such calculations enable us to develop a cumulative density function for spatial probability of landslides.

2.1.3 Damages due to landslides

As suggested by Chaturvedi et al. (2016), the damages caused by landslides were classified into three independent categories: property loss, injury, and fatality. These categories have their own damage probabilities. When a landslide occurs, it could be benign or catastrophic. A landslide becomes catastrophic when any of the three independent random numbers (~ $U(0, 1)$) become less than or equal to the corresponding damage probability of property loss, injury, and fatality. Once the random number is less than the probability of the corresponding damage, the damage occurs. Landslide damages have different effects on the player's wealth and income, where damage to property affects one's property wealth and damages concerning injury and fatality affect one's income level.

2.2 Interactive Landslide Simulator (ILS) tool

The ILS tool (Chaturvedi et al., 2016) is based upon the ILS model described above and allows participants to make daily monetary investment decisions for landslide risk-mitigation, observe the consequences of their decisions via feedback, and try new investment decisions. This way, ILS helps improve people's understanding about the causes and consequences of landslides.

A decision maker's goal in ILS tool is to maximize their total wealth, where this wealth is influenced by one's income, property wealth, and losses experienced due to landslides. Landslides and corresponding losses are influenced by physical factors (spatial and temporal probabilities of landslides) and human factors (i.e., the past contributions made by a decision-maker for landslide mitigation). The total wealth may decrease (by damages caused by landslides, like injury, death, and property damage) or increase (due to daily income). While interacting with the tool, the repeated feedback on the positive or negative consequences of their decisions on their income and property wealth enables decision-makers to revise their decisions and learn landslide risks and dynamics over time.

Figure 2 represents graphical user interface of ILS tool's investment screen. On this screen, decision-makers are asked to make monetary mitigation decisions up to their daily income upper bound (see Box A). The total wealth is a sum of income not invested for landslide mitigation, property wealth, and total damages due to landslides (see Box B). As shown in Box B, decision-makers are also shown the different probabilities of landslide due to human and physical factors as well as the probability weight used to combine these probabilities into the total probability. Furthermore, as shown in Box C, participants are graphically shown the history of total probability of landslide, total income not invested in landslides, and their remaining property wealth across different days.

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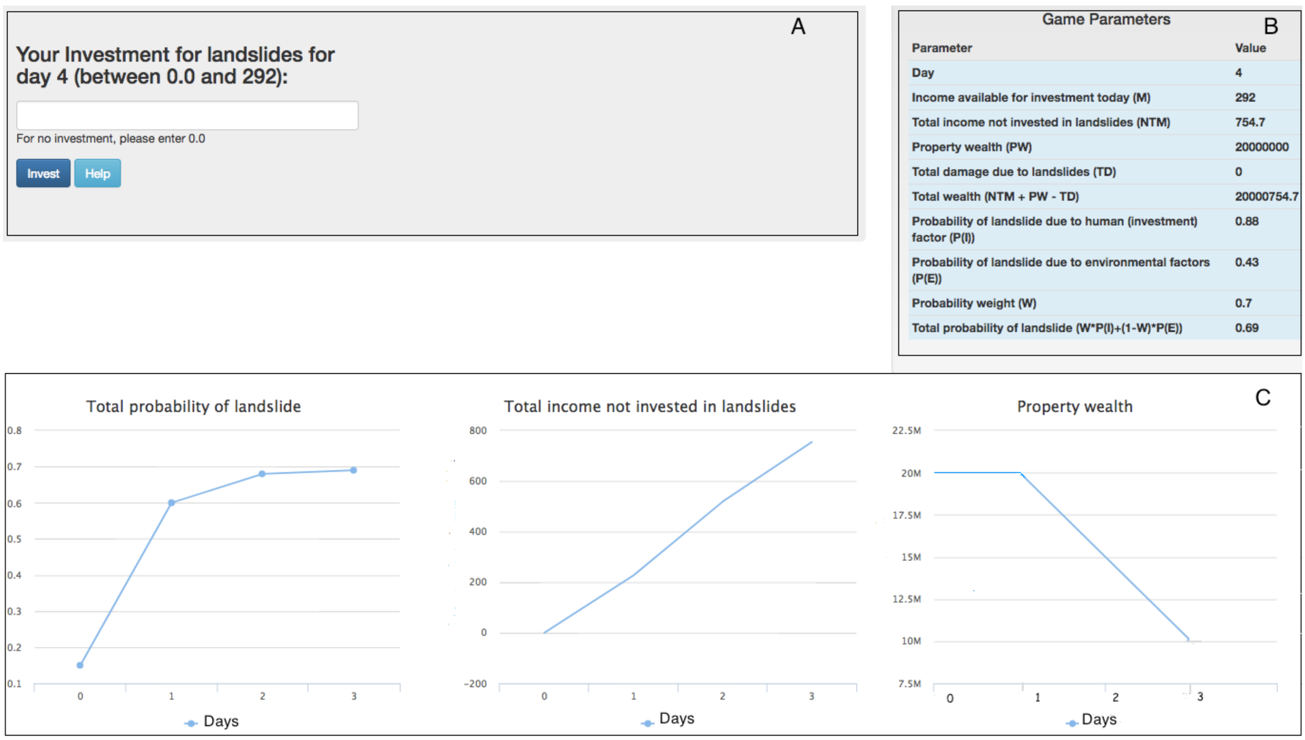

Figure 2. ILS tool's Investment Screen. Box **(A):** The text box where participants made investments against landslides. Box **(B):** The tool's different parameters and their values. Box **(C):** Line graphs showing the total probability of landslide, the total income not invested in landslides, and the property wealth over days. Horizontal axes in these graphs represents number of days. The goal was to maximize Total Wealth across a number of days of performance in the ILS tool.

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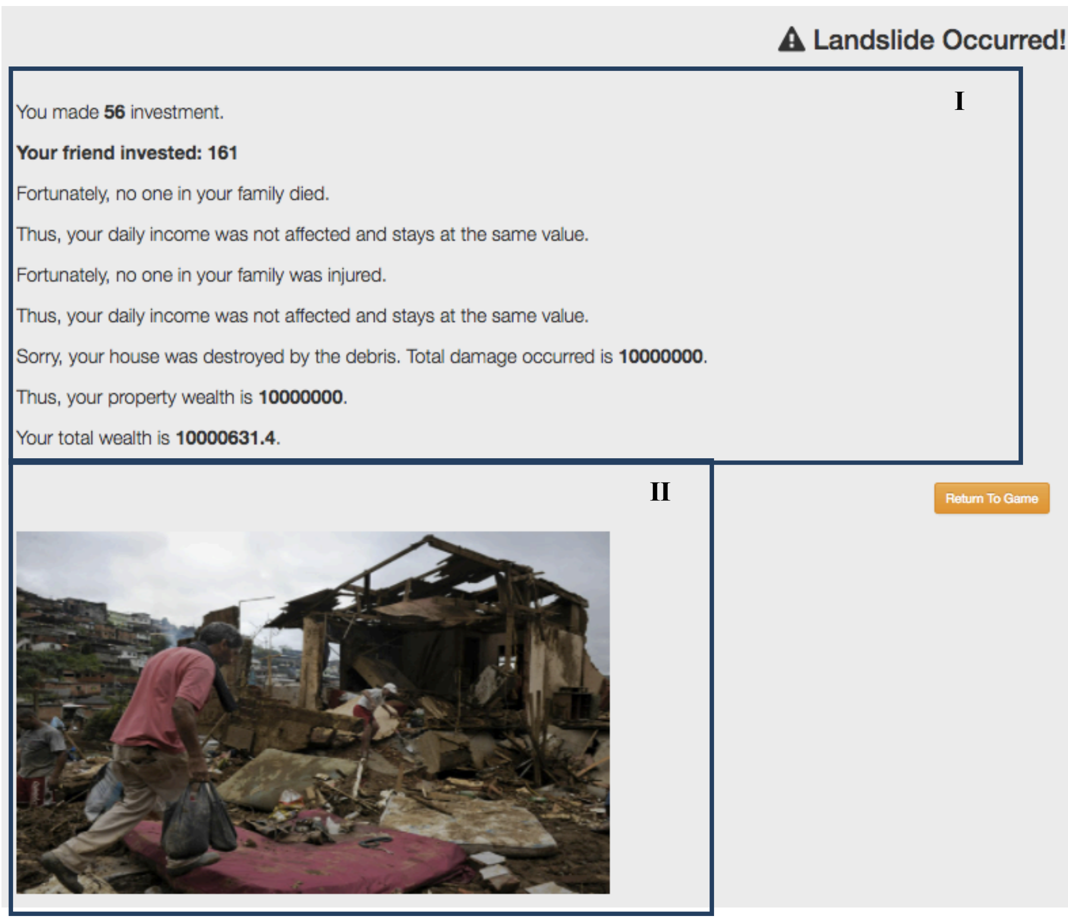
As described above, a decision-maker can invest between zero (minimum) and player's current daily income (maximum). Once the investment is made, participants need to click the "Invest" button. Upon clicking the Invest button, the decision-maker enters the experiential feedback screen and can observe whether landslide occurred or not and whether there were changes in the daily income, property wealth, and damages due to the landslide (see Figure 3). As shown in Figure 3 (A), feedback information is presented in three formats: monetary information about total wealth (box I), messages about different losses (box I), and imagery corresponding to losses (box II). Injury and fatality due to landslides causes a decrease in the daily income and damage to property causes a loss of property wealth (the exact loss proportions are detailed ahead). If a landslide does not occur in a certain trial, a positive feedback screen is shown to the decision maker (see Figure 3B). The user can get back to investment decision screen by clicking on "Return to Game" button on the feedback screen.

(A) Negative Feedback



(B) Positive Feedback

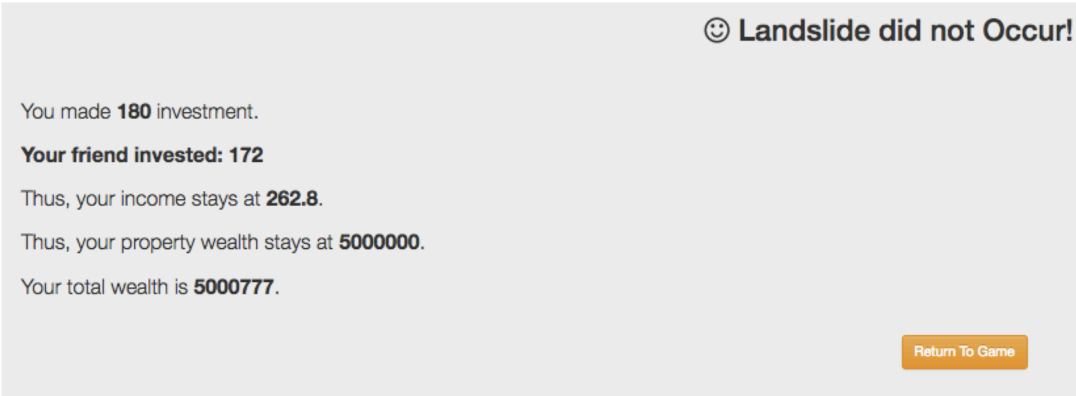


Figure 3. ILS tool's feedback screens. **(A)** Negative feedback when a landslide occurred. Box (I) contains the loss in terms of magnitude and messages and Box (II) contains associated imagery. **(B)** Positive feedback when a landslide did not occur.

3 Experiment

To test the effectiveness of amount and availability of feedback, we performed a laboratory experiment involving human participants where we compared performance in the ILS tool in the presence or absence of experiential feedback about different damage probabilities. Based upon prior literature (Baumeister et al., 2007; Dutt and Gonzalez, 2012; Finucane et al., 2000; Knutty, 2005; Reis and Judd, 2013; Wagner, 2007), we expected proportion of investments to be higher in the presence of experiential feedback compared to those in the absence of experiential feedback. Furthermore, we expected higher investments against landslides when feedback was more damaging in ILS compared to when it was less damaging (Chaturvedi et al., 2016; Dutt and Gonzalez, 2011; Gonzalez and Dutt, 2011a).

3.1 Experimental Design

Eighty-three participants were randomly assigned across four between-subjects conditions in the ILS tool, where the conditions differed in the amount of experiential feedback (high-damage (N= 40) or low-damage (N= 43)) and availability of feedback (feedback-present (N= 43) or feedback-absent (N= 40)) provided after every mitigation decision. They were asked to invest repeatedly against landslides across 30-days. In feedback-present conditions, participants performed in the ILS tool, where they received experiential feedback after each investment decision (see Figure 2). In feedback-absent conditions, participants again performed in the ILS tool; however, they did not receive experiential feedback after each investment decision (see Figure 4). Thus, in the feedback-absent condition, although participants were provided with the probability of damages due to landslides and the results of 0% and 100% investments as a text description; however, there was no feedback screen as well as graphical displays to provide experiential feedback to participants. In high-damage conditions, the probability of property damage, fatality and injury on any trial were set at 30%, 9%, and 90%, respectively, over 30-days. In low-damage conditions, the probability of property damage, fatality and injury on any trial were set at 3%, 1%, and 10%, respectively, over 30-days (i.e., about 1/10th of its values in the high-damage condition). Across all conditions, participants made one investment decision per trial across 30-days (this end-point was unknown to participants). Participants' goal was to maximize their total wealth over 30-days. Across all conditions, only 1-landslide could occur on a particular day. The nature of functional forms used for calculating different probabilities in ILS were unknown to participants.

The proportion of damage (in terms of daily income and property wealth) that occurred in an event of fatality, injury, or property damage was kept constant across 30-days. The property wealth decreased to half of its value every time property damage occurred in an event of a landslide. The daily income was reduced by 10% of its latest value due to a landslide-induced injury and 20% of its latest value due to a landslide-induced fatality. The initial property wealth was fixed to 20 million EC[1], which is the expected property wealth in Mandi area. The initial per-trial income was kept at 292 EC (taking into account the GDP and per-capita income of Himachal state where Mandi is located). Overall, there was a large difference between the initial income earned by a participant and the participant's initial property wealth. In this scenario, the optimal strategy dictates participants to invest their entire income in landslide protection measures, since participants' goal was to maximize total wealth. Weight (W) parameter was fixed at 0.8. The W value was known to participants on the graphical user interface (see Figures 2 and 4). Furthermore, the return to mitigation parameter (M) was set at 0.8. Participants performed in the ILS for 30-days, starting in mid-July and ending in mid-August. This period coincided with the period of heavy monsoon rainfall in Mandi area. Thus, participants performing in ILS experienced an increasing probability of landslides due to environmental factors (due to increasing amount of rainfall overtime). We used the investment ratio as a dependent variable for the purpose of data analyses.

The investment ratio was defined as the ratio of investment made in a trial to total investment that could have been made up to the same trial. This investment ratio was averaged across all participants in one case and averaged over all participants and days in another case. We expected the average investment ratio to be higher in the feedback-present and high-damage conditions compared to feedback-absent and low-damage conditions.

[1] To avoid the effects of currency units on people's decisions, we converted Indian National Rupees (INR) to a fictitious currency called "Electronic Currency (EC)," where 1 EC = 1 INR.

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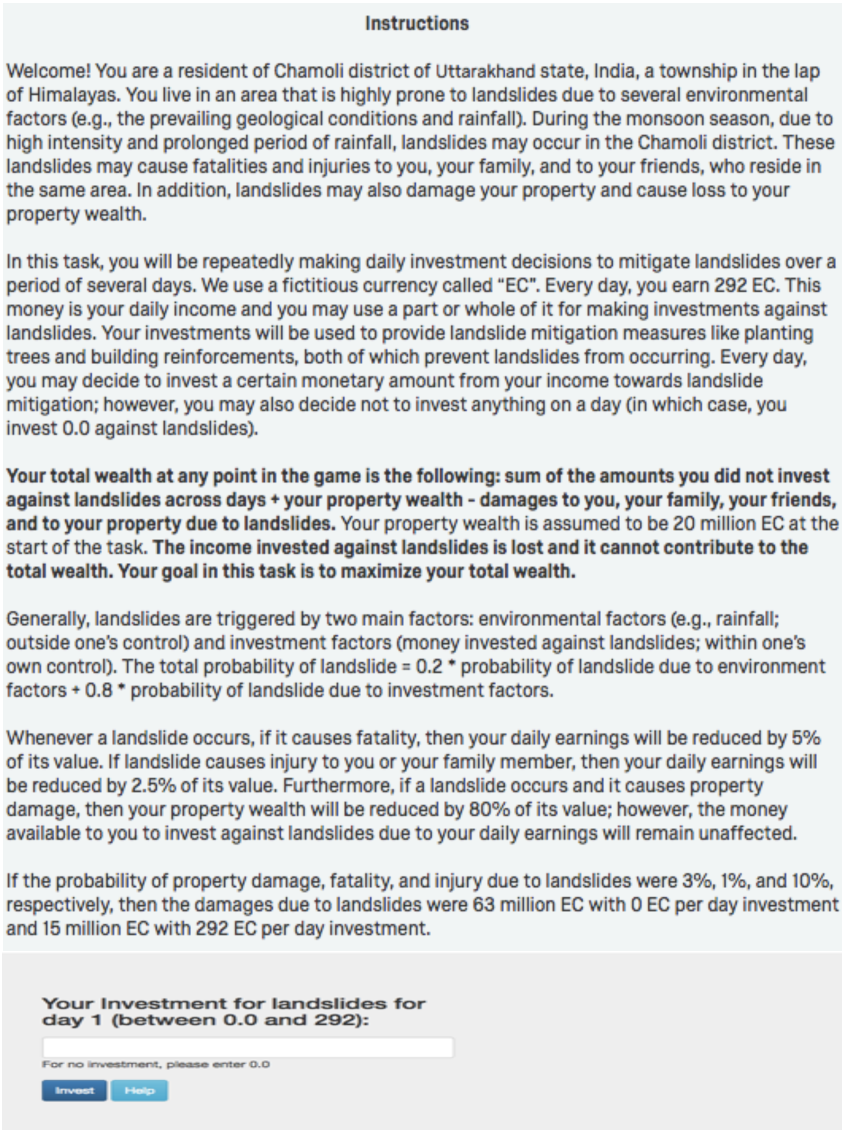

Figure 4. The ILS tool in the feedback-absent condition. Participants were tasked to enter across 30-days how much out of 292 EC they were willing to contribute against landslides. The task was similar in the high-damage feedback-absent condition; however, the damage percentages in the last paragraph were 30%, 9%, and 90%, respectively.

3.2 Participants

Participants were recruited from Mandi area via an online advertisement. The research was approved by the Ethics Committee at Indian Institute of Technology Mandi. Informed consent was obtained from each participant and participation was completely voluntary. All participants were from Science, Technology, Engineering, and Mathematics (STEM) backgrounds and their ages ranged in between 21 and 28 years (Mean = 22 years; Standard

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Deviation = 2.19 years). The following percentage of participants were pursuing or had completed different degrees: 6.0% high-school degrees; 54.3% undergraduate degrees; 33.7% Master's degrees; and, 6.0% Ph.D. degrees. When asked about their previous knowledge about landslides, 2.4% claimed to be highly knowledgeable, 16.8% claimed to be knowledgeable, 57.8% claimed to have basic understanding, 18.2% claimed to have little understanding, and 4.8% claimed to have no idea. All participants received a base payment of INR 50 (~ USD 1). In addition, there was a performance incentive based upon a lucky draw. Top-10 performing participants based upon total wealth remaining at the end of the study were put in a lucky draw and one of the participants was randomly selected and awarded a cash prize of INR 500. Participants were told about this performance incentive before they started their experiment.

3.3 Procedure

Participants were recruited via an online advertisement. Experimental sessions were about 30-minutes long per participant. Participants were given instructions on the computer screen and were encouraged to ask questions before starting their study (See Appendix "A" for text of instructions used). Once participants had finished their study, they were asked questions related to what information and decision strategy they used on the investment screen and the feedback screen to make their decisions. Once participants ended their study, they were thanked and paid for their participation.

4 Results

4.1 Investment Ratio Across Conditions

The data were subjected to a 2 × 2 repeated-measures analysis of variance. As shown in Figure 5A, there was a significant main effect of feedback's availability: the average investment ratio was higher in feedback-present conditions (0.53) compared to that in feedback-absent conditions (0.37) (F (1, 79) = 8.86, $p < 0.01$, $\eta^2 = 0.10$). This result is as per our expectation and shows that the presence of experiential feedback in ILS tool helped participants increase their investments against landslides compared to investments in the absence of this feedback.

As shown in Figure 5B, there was a significant main-effect of amount of feedback: the average investment ratio was significantly higher in high-damage conditions (0.51) compared to that in low-damage conditions (0.38) (F (1, 79) = 5.46, $p < 0.05$, $\eta^2 = 0.07$). Again, this result is as per our expectation and shows that high-damaging feedback helped participants increase their investments against landslides compared low-damaging feedback.

Furthermore, as shown in Figure 5C, the interaction between the amount of feedback and feedback's availability was significant (F (1, 79) = 8.98, $p < 0.01$, $\eta^2 = 0.10$). There was no difference in the investment ratio between the high-damage condition (0.35) and low-damage condition (0.38) when experiential feedback in ILS was absent; however, the investment ratio was much higher in the high-damage condition (0.67) compared to the low-damage condition (0.38) when experiential feedback in ILS was present. Thus, feedback needed to be damaging in

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ILS to cause an increase in investments in mitigation measures against landslides.

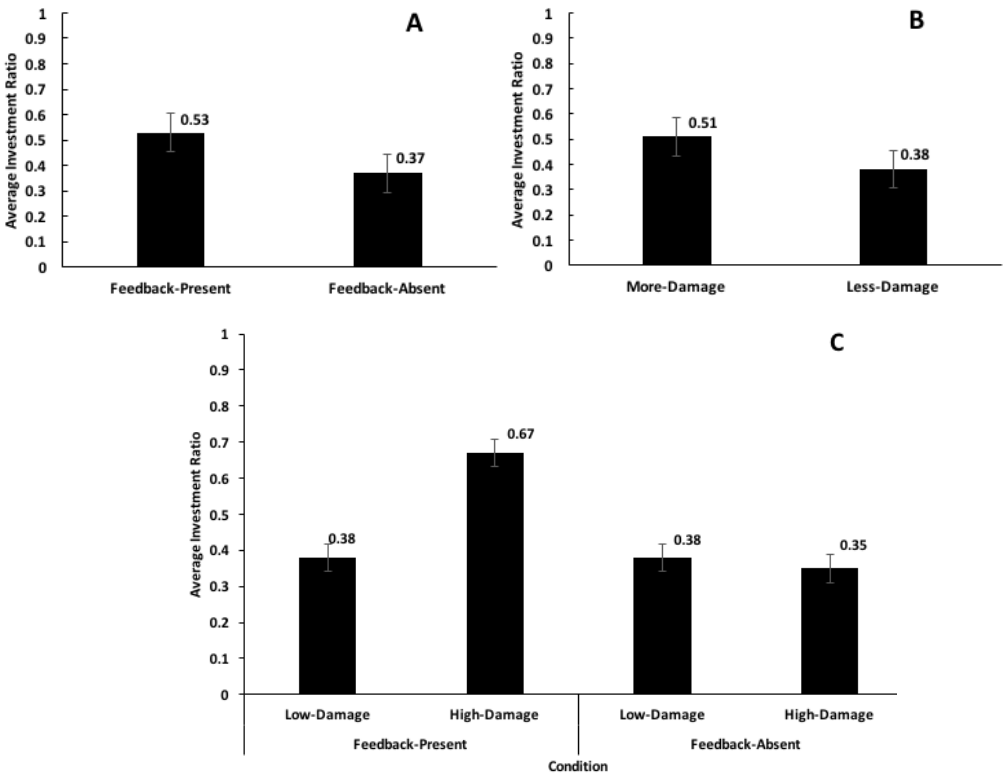

Figure 5. (A) Average investment ratio in Feedback-present and Feedback-absent conditions. **(B)** Average investment ratio in low- and high-damage conditions. **(C)** Average investment ratio in low- and high-damage conditions with Feedback-present and absent. The error bars show 95% CI around the point estimate.

4.2 Investment Ratio Across Days

The average investment ratio increased significantly over 30-days (see Figure 6A; F (8.18, 646.1) = 8.35, $p < 0.001$, $\eta^2 = 0.10$). As shown in Figure 6B, the average investment ratio increased rapidly over 30-days in feedback-present conditions; however, the increase was marginal in feedback-absent conditions (F (8.18, 646.1) = 3.98, $p < 0.001$, $\eta^2 = 0.05$). Furthermore, in feedback-present conditions, the average investment ratio increased rapidly over 30-days in high-damage conditions; however, the increase was again marginal in the low-damage conditions (see Figure 6C; F (8.18, 646.1) = 6.56, $p < 0.001$, $\eta^2 = 0.08$). Lastly, as seen in Figure 6D, although there were differences in the increase in average investment ratio between low-damage and high-damage conditions when experiential feedback was present; however, such differences were non-existent between the two damage conditions when experiential feedback was absent (F (8.18, 646.1) = 4.16, $p < 0.001$, $\eta^2 = 0.05$). Overall, ILS performance helped participants increase their investments for mitigating landslides when damage feedback was high compared to low in ILS. However, in feedback's absence in ILS, participants were unable to increase their investments for mitigating landslides, even when damages were high compared to low.

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4.3 Participant Strategies

We analyzed whether an "invest-all" strategy (i.e., investing the entire daily income in mitigating landslides) was reported by participants across different conditions. As mentioned above, the invest-all strategy was an optimal strategy and this strategy's use indicated learning in the ILS tool. Figure 7 shows the proportion of participants reporting the use of the invest-all strategy. Thus, many participants learnt to follow the invest-all strategy in conditions where experiential feedback was present and it was highly damaging compared to participants in the other conditions.

5 Discussions and Conclusion

In this paper, we used an existing Interactive Landslide Simulator (ILS) tool for evaluating the effectiveness of feedback in influencing people's decisions against landslide risks. We used the ILS tool in an experiment involving human participants and tested how the amount and availability of experiential feedback in ILS, including the use of ILS tool itself, helped increase people's investment decisions against landslides. Our results agree with our expectations: Experience gained in ILS enabled improved understanding of processes governing landslides and helped participants improve their investments against landslides. Given our results, we believe that ILS could potentially be used as a landslide-education tool for increasing public understanding and awareness about landslides. The ILS tool can also be used by policymakers to do what-if analyses in different scenarios concerning landslides.

First, high-damaging feedback in ILS tool helped increase people's investment against landslides over time compared to low-damaging feedback in the tool. Furthermore, the experiential feedback helped participants increase their investments against landslides compared to conditions where this feedback was absent. These result can be explained by previous lab-based research on use of repeated feedback or experience (Chaturvedi et al., 2016; Dutt and Gonzalez, 2010, 2011; Finucane et al., 2000; Gonzalez and Dutt, 2011a). Repeated experiential feedback likely enables learning by repeated trial-and-error procedures, where participants try different investment values in ILS and observe their effects on occurrence of landslides. This feedback is higher in the condition when damages are more compared to when damages are less and this difference in feedback influences participant investments against landslides. In fact, we observed that the use of the optimal invest-all strategy was maximized when the experiential feedback was highly damaging.

We also believe that the ILS tool can be integrated in teaching courses on landslide sustainable practices in K-12 schools. This course could make use of the ILS tool and focus on educating students about causes, consequences, and risks of hazardous landslides. We believe that the use of ILS tool will make teaching more effective as ILS will help incorporate experiential feedback and social norms in teaching in interactive ways.

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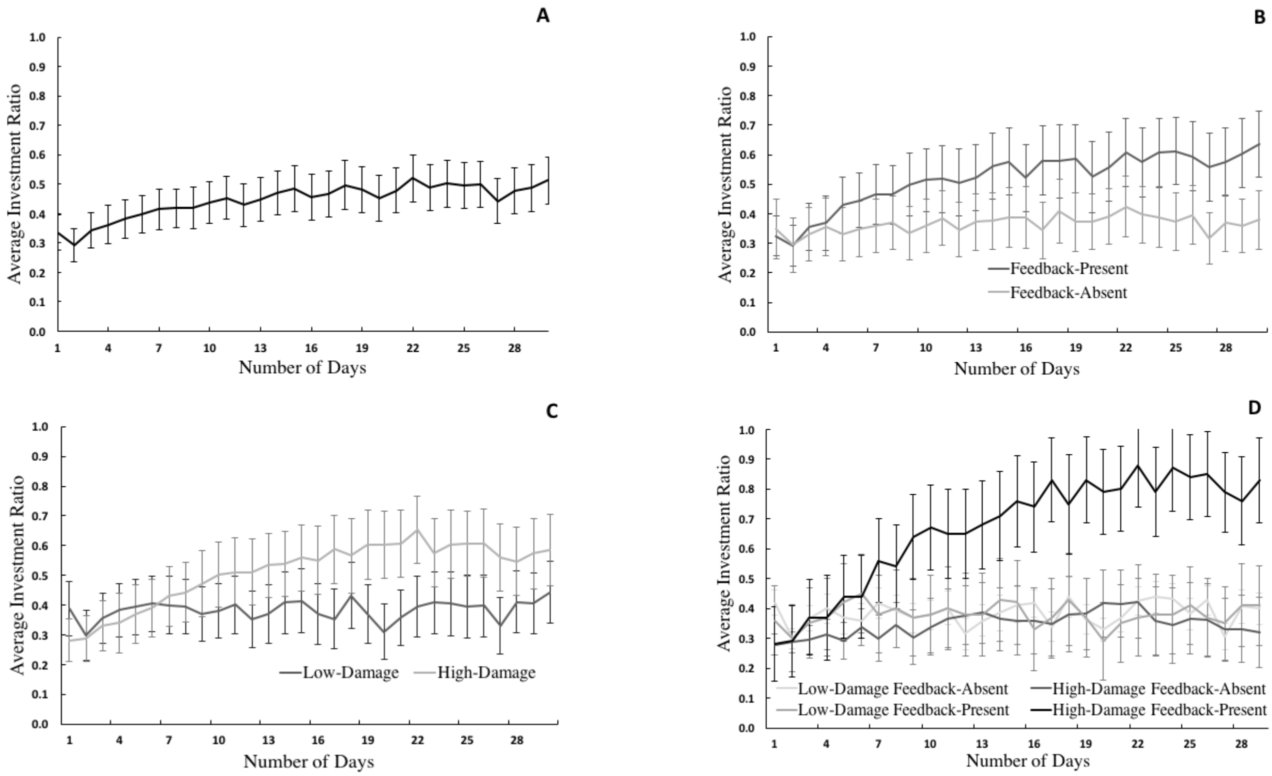

Figure 6. (A) Average investment ratio over days. **(B)** Average investment ratio over days in Feedback-present and Feedback-absent conditions. **(C)** Average investment ratio over days in low- and high-damage conditions. **(D)** Average investment ratio over days in low- and high- damage conditions with Feedback-present or absent. The error bars show 95% CI around the point estimate.

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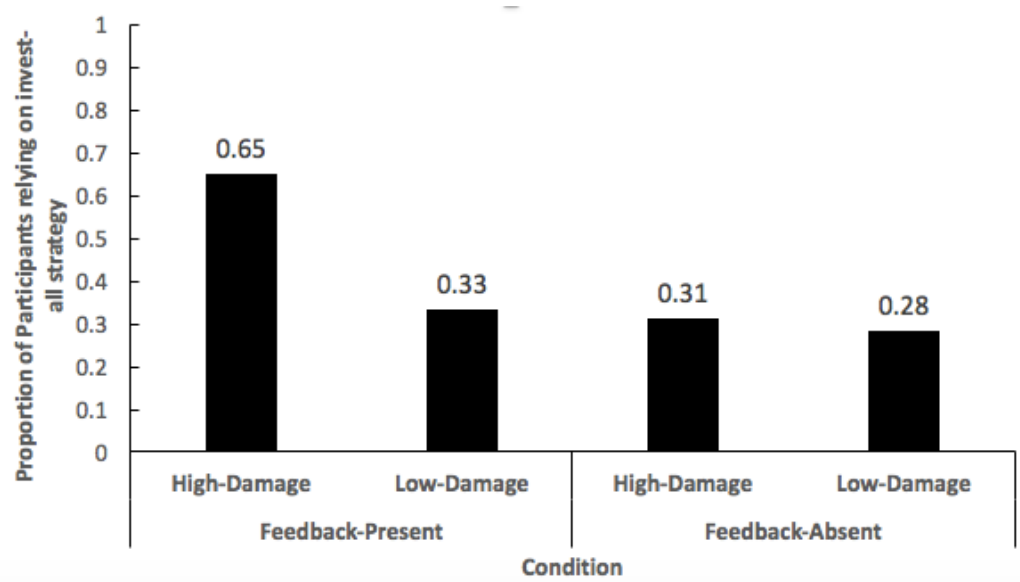

Figure 7. The proportion of reliance on the invest-all strategy across different conditions.

The ILS tool's parameter settings could be customized to a certain geographical area over a certain time period of play. In addition, the ILS tool could be used to present investment actions of other decision-makers (e.g., society or neighbours) compared to one's own investment actions. The presence of investment of other decision-makers in addition to one's own decisions will likely enable the use of social norms towards learning (Schultz et al., 2007). These features makes ILS tool very attractive for landslide education in communities in the future.

Furthermore, the ILS tool holds a great promise for policy-research against landslides. For example, in future, researchers may vary different system-response parameters in ILS (e.g. weight of one's decisions and return to mitigation actions) and feedback (e.g. numbers, text messages and images for damage) in order to study their effects on people's decisions against landslides. Here, researchers could evaluate differences in ILS's ability to increase public contributions in the face of other system-response parameters and feedback. In addition, researchers can use the ILS tool to do "what-if" analyses related to landslides for certain time periods and for certain geographical locations. The ILS tool has the ability to be customized to certain geographical area as well as certain time periods, where spatial parameters (e.g., soil type and geology) as well as temporal parameters (e.g., daily rainfall) can be defined for the area of interest. Once the environmental factors have been accounted for, the ILS tool enables researchers to account for assumptions on human factors (contribution against landslides) with real-world consequences (injury, fatality, and infrastructure damage). Such assumptions may help researchers model human decisions in computational cognitive models, which are based upon influential theories of how people make decisions from feedback (Dutt and Gonzalez, 2012; Gonzalez and Dutt, 2011b). In summary, these features make ILS tool apt for policy research, especially for areas that are prone to landslides. This research will also help test the ILS tool and its applicability in different real-world settings.

Although we could investigate that the ILS tool causes the use of optimal invest-all strategies among people in conditions where experiential feedback is highly damaging; however, future research should focus on investigating more deeply about the nature of learning that the tool imparts among people. As people's investments for mitigating landslides in ILS directly influences the risk of landslides due to human and environmental factors, investments indeed have the potential of educating people about landslide risks. Still, it is important to investigate how investing money in the ILS tool truly educates people about landslides.

In addition, it would be worthwhile investigating how people's decision-making evolves in conditions where investments influence the landslide probability and in conditions where investments do not influence the landslide probability much. Some of these ideas form the immediate next steps in our ongoing program on landslide risk communication.

Data availability. Data used in this article have not been deposited to respect the privacy of users. The data can be provided to readers upon request.

Author contributions. AA designed the website, administered the account, PC wrote the first draft of website articles and collected data. VD supervised the website contents. AA provided technical support for website maintenance. PC and VD analysed the data and prepared the manuscript. PC revised the manuscript.

Competing interests. The authors declare that they have no conflict of interest.

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Appendix A

Instructions of the Experiment

Welcome!

You are a resident of Mandi district of Himachal Pradesh, India, a township in the lap of Himalayas. You live in an area that is highly prone to landslides due to a number of environmental factors (e.g., the prevailing geological conditions and rainfall). During the monsoon season, due to high intensity and prolonged period of rainfall, a number of landslides may occur in the Mandi district. These landslides may cause fatalities and injuries to you, your family, and to your friends, who reside in the same area. In addition, landslides may also damage your property and cause loss to your property wealth.

This study consists of a task, where you will be making repetitive decisions to invest money in order to mitigate landslides. Every trial, you'll earn certain money between 0 and 10 points. This money is available to you to invest against landslides. You may invest certain amount from the money available to you; however, if you do not wish to invest anything, you may invest 0.0 against landslides on a particular trial. Based upon your investment against landslides, you'll get feedback on whether a landslide occurred and whether there was an associated loss of life, injury, or property damage (all three events are independent and they can occur at the same time).

Your total wealth at any point in the game is the following: sum of the amounts you did not invest against landslides across days + your property wealth - damages to you, your family, your friends, and to your property due to landslides. Your property wealth is assumed to be 100 points at the start of the game. The amount of money **not invested against landslides** increases your total wealth. **Your goal is to maximize your total wealth in the game**.

Whenever a landslide occurs, if it causes fatality, then your daily earnings will be reduced by 5% of its present value at that time and if landslide causes injury to someone, then the daily earnings willbe reduced by 2.5% of its present value at that time. Thus, the amount available to you to invest against landslides will reduce with each fatality and injury due to landslides. Furthermore, if a landslide occurs and it causes property damage, then your property wealth will be reduced by 80% of its present value at that time; however, the money available to you to invest against landslides due to your daily earnings will remain unaffected.

Generally, landslides are triggered by two main factors: environmental factors (e.g., rainfall; outside one's control) and investment factors (money invested against landslides; within one's own control). The total probability of landslide is a weighted average of probability of landslide due to environment factors and probability of landslide due to investment factors. The money you invest against landslides reduces the probability of landslide due to investment factors and also reduces the total probability of landslides. However, the money invested against landslides is lost and it cannot become a part of your total wealth.

At the end of the game, we'll convert your total wealth into INR and pay you for your effort. For this conversion, a ratio of 100 total wealth points = INR 1 will be followed. In addition, you will be paid INR 30 as base payment for your effort in the task. Please remember that your goal is to maximize your total wealth in the game.

Starting Game Parameters

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Your wealth: **20 Million**

When a landslide occurs:

If a death occurs, your daily income will be reduced by **50**% of its current value.

If an injury takes place, your daily income will be reduced by **25**% of its current value.

If a property damage occurs, your wealth will be reduced by **50**% of your property wealth.

Best of Luck!