Raising Environmental Awareness with Augmented Reality*

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Abstract

Individuals are often poorly informed about the environmental consequences of their actions. Informational campaigns are a widely used policy tool to address imperfect information. However, previous research suggests that simply providing information may be ineffective and fail to engage individuals. We investigate whether augmented reality (AR) can reduce psychological distance and promote pro-environmental behavior. In two incentivized experiments (laboratory and contextualized), we evaluate the effect of AR visualizations of marine plastic-pollution consequences on participants' psychological distance and donations to pro-environmental organizations. These measures are complemented by self-reported environmental concern, pro-environmental engagement, intention to act, and prior experience with AR technology. Our results show no significant impact of AR visualizations on psychological distance or donation levels in either the AR-Lab or AR-Context settings. Consistent with these behavioral findings, we observe no significant differences across experimental conditions in self-reported measures. Interestingly, we document a general optimism regarding the effectiveness of immersive technologies as policy tools, highlighting a potential misalignment between public expectations and the actual effectiveness of these technologies.

Keywords: pro-environmental behavior; environmental decision-making; experiment; fundraising; augmented reality; psychological distance

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1 Introduction

Plastic pollution is one of the fastest growing environmental problems of our society (Khedr et al., 2023; Jambeck et al., 2015). The estimated total amount of plastic being produced in the world amounts to 400 million metric tons, roughly equivalent to the weight of all humans on the planet (OECD, 2022). A substantial proportion of such plastic flows into oceans, negatively affecting wildlife and humans (Gregory, 2009; Rochman et al., 2013). Policymakers have taken actions to reduce the over-consumption of single-use plastic products, resorting to conventional policy tools, such as informational campaigns and public appeals (Abrahamse et al., 2005; Carlsson et al., 2021). However, besides constant warnings from leading global institutions, environmental policies often fail to achieve much-needed behavioral change. Despite receiving important information on appropriate conducts, individuals may overlook it, and eventually forget about it over time (Gabaix and Laibson, 2006; Guido et al., 2024). This is not surprising, as people often do not experience the consequences of environmental threats directly. Instead, they perceive these threats as remote and irrelevant – a phenomenon known as *psychological distance* (Carmi and Kimhi, 2015; Spence et al., 2012).

In search for alternatives to conventional policy measures, scholars in behavioral economics and psychology have offered numerous insights to promote pro-environmental interventions (Gintis, 2000; Venkatachalam, 2008; Bhargava and Loewenstein, 2015). Research has highlighted the importance of communicating environmental issues in ways that are concrete and visual to reduce psychological distance (Akerlof et al., 2013; van der Linden et al., 2015). This idea is grounded in Construal Level Theory (CLT) (Trope and Liberman, 2010), which provides a theoretical framework to understand the link between psychological distance and behavior. According to CLT, if individuals perceive environmental problems, such as climate change or plastic pollution, as distant and abstract, they reduce their urge of taking pro-environmental actions. A behavioral solution that can fill the psychological gap is the use of virtual immersive technologies, such as augmented reality (AR). By overlaying reality with virtual objects, AR technologies offer a sense of "situatedness" (Goel et al., 2012), which increases individuals' connection to current environmental issues. Despite this potential, to our knowledge, no experimental study has investigated whether AR technologies reduce psychological distance and whether this reduction mediates the effect of AR on pro-environmental behavior.

This study aims to compare the effectiveness of traditional text-based appeals with AR visualizations in promoting pro-environmental behavior. The vast majority of experimental studies on the impact of immersive technologies on pro-environmental behavior utilize Virtual Reality (VR) technologies. However, AR offers advantages over VR, including easier deployment, lower cost, and greater accessibility via everyday devices like smartphones and tablets (Furht, 2011). Our AR application, installed on tablets, illustrates the consequences of marine plastic pollution: the visual content takes the form of the five most affected animals – a sea turtle, a bird, a dolphin, a whale or a seal – entangled in single-use plastics (Gall and Thompson, 2015).

Building on CLT, we test whether such AR visualizations reduce psychological distance to marine plastic pollution, an in turn promote donations to environmental organizations. In a laboratory experiment, we let participants engage with immersive AR visualizations depicting the consequences of plastic pollution on marine wildlife. Following this intervention, we measure psychological distance, actual pro-environmental behavior assessed through voluntary donations to an environmental organization, and a set of self-reported metrics.[1]

The results of the laboratory experiment shed light on both behavior change and general attitudes towards AR technologies. First, we show that AR visualizations produce no significant change on psychological distance relative to text-based appeals. Similarly, we find no significant change in donation levels and no evidence of a mediating effect of psychological distance.

As a robustness check, we test whether these results hold in a more natural environment, outside the neutral, context-free laboratory setting. We replicate the AR treatment in a context closer to the natural habitat of marine animals, i.e., on the beach, where the AR experience might appear more natural and realistic. Results hold unchanged, corroborating the idea that our AR visualizations are not effective in reducing psychological distance or bringing about behavioral change. We also explore whether participants' concern for marine plastic pollution and policy support have changed. Consistently with our behavioral findings, we observe no significant differences across experimental conditions in any of these self-reported measures.

While our work adds to previous research showing that altering pro-environmental behavior through immersive visualizations can be challenging (Brambilla et al., 2024; Dunn et al., 2021; van Horen et al., 2024), less is understood regarding public perceptions of these technologies' effectiveness. Policymakers and organizations are increasingly advocating for these technologies as a means to motivate action.[2] This emerging trend indicates that the public perceives immersive technologies as more effective than traditional tools and may be more likely to endorse and support such interventions. To explore this question, we measure beliefs about whether immersive technologies (i.e., AR and VR) are more effective than simple text-based appeals in raising donations. Our results reveal that individuals expect immersive technologies to be more effective at encouraging environmental donations compared to text-based appeals. This perceived advantage of immersive technologies is particularly pronounced

[1] We focused on nonprofit organizations since they are one of the key players in motivating public environmental engagement (Osuri, 2010; Nisbet, 2018) and the success of their initiatives calls for a detailed understanding of the motivational forces behind people's decision to donate money (Verssimo et al., 2018; Freeling and Connell, 2020).

[2] As an example, to improve the learning experience in its training program, the US Department of Agriculture has started using VR to transform a traditional classroom course on public health veterinary. Defense agencies have been using a combination of digital reality technologies to train soldiers and medical professionals (Briggs et al., 2018).

among participants who experienced AR firsthand during our experiment.

This work suggests important theoretical and practical implications. First, we contribute to the current debate around the use of immersive technologies in raising awareness about environmental risks. While previous studies have demonstrated positive evidence regarding the effectiveness of AR visualizations (Levstek et al., 2024), this body of literature remains fragmented and inconclusive (Brambilla et al., 2024; van Horen et al., 2024). We contribute to this debate by shedding light on the role played by psychological distance, a factor put forward by past theoretical work in the environmental literature (Spence et al., 2012), and showing the limits of immersive technologies. Second, our findings highlight the importance of setting realistic expectations for AR interventions. While the opinion about the use of AR can be particularly optimistic, the direct impact of AR on behavioral changes, such as financial contributions or policy support, may be limited. This suggests that research on the effect of AR is needed and that immersive technologies do not yet represent a replacement for traditional strategies to incentivize or mandate pro-environmental actions. Third, this study highlights a critical misalignment between public expectations and the actual effectiveness of immersive technologies, such as AR and VR, in driving pro-environmental behavior. Our results show that individuals expect these technologies as more effective than traditional tools, a discrepancy that does not emerge when looking at actual behavior in the case of our AR intervention. The divergence between expectations and behavior can lead to inefficient allocation of resources by policy makers and organizations.

The rest of the paper is organized as follows. Section 2 outlines our conceptual framework and hypotheses, explaining how immersive technologies can reduce psychological distance and thereby serve as effective tools in the field of behavioral ecological economics. Section 3 describes our laboratory and contextualized experiments. Section 4 reports the results. Lastly, Section 5 concludes.

2 Conceptual Framework and Hypotheses

2.1 Construal Level Theory, Psychological Distance and Pro-Environmental Behavior

Communicating ecological and environmental issues to people is often challenging due to their abstract nature and the disconnect between causes and consequences. Environmental threats are rarely experienced directly. For instance, individuals in remote areas often feel less affected by marine plastic pollution because these regions typically have sparse populations and minimal industrial activity (Abate et al., 2020). Research suggests that the lack of direct experience leads individuals to perceive environmental problems as temporally, socially or spatially distant events, which hinders the formation of sustainable behavioral intentions and ultimately the adoption of pro-environmental actions (Carmi and Kimhi, 2015). This phenomenon is often referred to as *psychological distance*, which finds its theoretical foundations in the Construal Level Theory (Trope and Liberman, 2010). Construal Level Theory (CLT) describes the impact of mental constructs and psychological distance on individual decisions. It assumes that when individuals do not experience something directly, but think about it, remember it or imagine it, they create abstract mental constructs to process and understand a phenomenon. Construals can be of two types: high-level construals, which are abstract and generic, and low-level construals which are detailed and specific. According to CLT, psychological distance can modulate the level of mental construals. As an example, if a subject is psychologically close to us, its mental construal becomes more concrete and psychologically closer. CLT outlines four key dimensions: 1) spatial or geographical distance, 2) temporal distance, 3) social distance, which refers to the gap between the perceiver and a social target – either an individual or a group, and 4) uncertainty, which pertains to how certain or hypothetical an event's occurrence is. Furthermore, CLT assumes that psychologically distant and close stimuli are represented in similar mental spaces and that the four dimensions are intertwined, such that an impact on one aspect of distance can influence the other aspects.[3]

There is a direct connection between psychological distance and pro-environmental behavior (for reviews, see McDonald et al., 2015; Maiella et al., 2020). Spence et al. (2012) analyzed survey data collected through computer-assisted personal interviews to examine the relationship between participants' perceived psychological distance from climate change and their levels of concern and willingness to act. The findings suggest that reducing psychological distance could be an effective strategy for motivating pro-environmental behavior, as it enhances concern about the issue. Other studies focus on specific dimensions of psychological distance. For example, Uzzell (2000) identifies an inverse relationship between a sense of responsibility for environmental problems and spatial scale, which leads to feelings of powerlessness at the global level. Tisserand et al. (2022) manipulated the spatial scale (local vs. national) of recommendations in a nationwide common pool resource experiment. Their findings indicate that individuals significantly reduce extraction levels in local as compared to national level dilemmas and that providing recommendations on sustainable extraction amounts significantly improves the sustainability of the resource. Yet, apart from a few exceptions, most of the extant studies focused on the change in behavioral intentions, and not on actual pro-environmental behavior. The link between psychological distance and environmental concerns suggests that policymakers should promote environmental engagement by filling knowledge gaps and making actions' consequences salient (van der Linden et al., 2015; Spence et al., 2012).

[3]Experimental evidence has shown that processing information about one dimension, say the geographical distance, is facilitated if people focus on distant congruent stimuli (e.g. socially or temporally distant or uncertain), suggesting that the four dimensions are cognitively associated (Bar-Anan et al., 2007).

2.2 Immersive Technologies to reduce Psychological Distance

The link between psychological distance and environmental concerns suggests that policymakers should promote environmental engagement by filling knowledge gaps and making actions' consequences salient (van der Linden et al., 2015; Spence et al., 2012). Traditional interventions based on information-provision strategies represent a viable solution (Carlsson et al., 2021). Previous experimental studies suggest that providing individuals with decision-relevant information brings about environmental behavioral change (Abrahamse et al., 2005; Andor and Fels, 2018; Staats et al., 1996). However, other studies report mixed findings and null effects of such behavioral interventions. One of the the major issues highlighted in the literature is that sheer information provision can be inconsequential, cognitively hard to digest and not engaging (Andor et al., 2022).

Immersive technologies offer a promising approach to addressing the limitations of information-based policy interventions. These technologies typically encompass VR and AR, collectively categorized under the broader term "extended reality" (Rauschnabel et al., 2022). While VR is fully immersive and transports users into a virtual environment by blocking vision with head-mounted goggles (Steuer, 1992), AR uses smart glasses or screens to blend the real and the virtual. It overlays reality with three-dimensional digital objects in real time to create the illusion that they are physically present (Azuma, 1997). Consistently with past theoretical work on embodied cognition (Merleau-Ponty, 1945; Varela et al., 1991; Clark, 2001; Gallagher, 2005), informational content presented in an interactive and vivid format can translate abstract mental constructs into concrete ones, bring distant places and future events closer, and vividly demonstrate the impact of environmental crises (Ahn et al., 2015).

Collectively, these factors indicate that AR fosters lower construal levels, thereby diminishing psychological distance. By narrowing psychological distance to environmental issues, it can be anticipated that individuals using AR will exhibit a greater willingness to engage in pro-environmental behaviors. Based on this reasoning, we propose the following hypotheses, with H2 relying on CLT from Section 2.1:

- H1: AR intervention reduces psychological distance
- H2: Psychological distance mediates the effect of AR on pro-environmental behavior

2.3 AR and VR experiments on pro-environmental behavior

The experimental literature on AR and VR has reported some encouraging results in promoting pro-environmental behavior. As highlighted in previous research (Buljat, 2022b; Cosio et al., 2023), the majority of experimental studies implementing immersive technologies focus on VR rather than AR. In 2021 alone, 22 papers using VR were published, compared to just 4 using AR (see Figure 1 in Cosio et al., 2023). Furthermore, according to the systematic review of Cosio et al. (2023), the vast majority of the extant studies focus on education and learning outcomes (around 62%), while only recently authors have started examining its influence on environmental concerns and beliefs (around 6%). This gap in the experimental literature regarding the impact of VR technologies on pro-environmental behavior motivates our study.

VR. The use of VR to foster pro-environmental behavior was first introduced by Fiore et al. (2009), who experimentally showed that virtual simulations of forest fire scenarios can reduce distortions in risk perceptions. Innocenti (2017) reviews research employing VR as a tool in experimental economics, making a distinction between low-immersive and high-immersive virtual environments. Subsequent studies explored the effects of low-immersive virtual environments (e.g., computer screens displaying videos) on internal factors such as a sense of spatial presence or emotional responses that influence pro-environmental intentions, support for environmental policies (Matthews et al., 2017; Meijers et al., 2023), and engagement with sustainable tourism (Chen et al., 2024). A few studies measured the impact of VR onto actual behavior. A pioneering work by Ahn et al. (2014) found that participants who virtually experienced cutting down a tree – with the help of a haptic device favoring interactivity – used 20% less paper compared to those reading a text. Later research demonstrated that immersive VR showing coral reefs or forests and the importance of protecting them can encourage donations (Nelson et al., 2020), particularly when combined with multisensory enhancements that foster a sense of embodying nature (Spangenberger et al., 2024). Stenberdt and Makransky (2023) used immersive VR to train high school students in waste sorting. More recent work by Faralla et al. (2024) demonstrate that VR can influence the perception of time, affecting decision-making for both personal and altruistic choices, depending on the immersive context. Other examples of works in this area that have addressed similar kind of behaviors are Meijers et al. (2023) and Plechatá et al. (2024), both focusing on sustainable dietary choices, Ibanez and Roussel (2022) on recycling headphone protectors, and van Horen et al. (2024), which failed to show any significant effect of VR on pro-environmental donations to an eco-NGO.[4] Studies suggest that immersive VR storytelling can increase climate change awareness (Dhunnoo et al., 2023; Xu et al., 2023) and engagement (Fernández Galeote et al., 2023), improve concern or positive attitudes about environmental issues (Markowitz et al., 2018), reduce gain-loss asymmetry in valuing land use change (Bateman et al., 2009), strengthen connections with nature (Ahn et al., 2016; Breves and Heber, 2020; Brambilla et al., 2024), or overall facilitate both the cognitive and affective variables necessary for change in environmental behavioral intentions (Hurrell et al., 2024) – see the survey of Grassini and Ratcliffe (2024).

AR. The evidence on the effect of AR on pro-environmental behavior has been

[4] Other works have studied VR effects in green investing (Vassilopoulos et al., 2023), plastic waste (Xiong et al., 2024), sea level rise (Calil et al., 2021) and flood risk perception (Mol et al., 2022).

less explored in the extant literature. In a longitudinal study, Levstek et al. (2024) investigated the effectiveness of an AR experience in promoting pro-environmental attitudes and behaviors. Authors compared the impact of the AR experience to a 2D video, and conducted a one-month follow-up survey. Results show that the AR group increased sustainability beliefs and pro-environmental behaviors immediately after and one month after the experience, exceeding the video group's improvements in some areas. In a related study, Dunn et al. (2021) evaluated the impact of an AR mobile game on pro-environmental behaviors, comparing it to a nature 2D video documentary. The study found that the AR mobile application was as effective as watching a nature documentary in increasing environmental knowledge, positive attitudes, and perceived behavioral control. However, this change did not translate into actual behavior, such as donations to conservation and wildlife-focused organizations, remarking the presence of an intention-behavior gap.

Besides the scattered evidence, to the best of our knowledge, there is no study that experimentally examined the effectiveness of AR in reducing psychological distance from environmental issues, and tested whether it translates into actual pro-environmental behavior.

3 Experimental Design

We designed a laboratory experiment to test the effects of AR on psychological distance and pro-environmental behavior. We tested whether participants' donations to environmental organizations were affected by AR visualizations showing the consequences of marine plastic pollution for the five most endangered animals (Gall and Thompson, 2015). The individual experiment was composed of several parts to collect pre-experimental measures, individual choices in a donation game, and self-reported attitudes towards plastic pollution. The whole experimental procedure is summarized in Figure 1. In the following, we describe the design and procedures of the experiment.

3.1 Pre-Experimental Questionnaire

In the first part, participants completed an initial questionnaire (*Pre-Experimental Questionnaire*), which collected their environmental engagement, donation experience and preferences for environmental organizations, familiarity with technologies, and other demographics. We outline below the main variables measured in the questionnaire. The text of each item can be found in Table A1 of Appendix A.

Environmental Engagement Score (EES). We measured participants' environmental engagement score using items inspired from Kaiser and Wilson (2000). The scale was created by calculating the mean of four questions related to participants' self-reported current environmental engagement: perception of being an environmentally conscious person; current level of environmental concern; current practices in purchasing eco-responsible products; recycling.[5] Responses to these items were highly internally consistent (Cronbach's $\alpha = 0.71$).[6]

Donation experience and preferred environmental organization. We asked participants to indicate whether they had previously donated to an environmental organization. The frequency of past donations was measured using a 5-point scale ranging from "never" to "more than 10 times". We also asked participants to select an organization they would donate to if given the opportunity. They could select it from a list of 12 well-known environmental organizations, primarily focused on plastic pollution and related issues, all of which accept donations through their websites.

Frequency of using related technologies. To assess familiarity and frequency of use of related technological devices and services, we asked participants to indicate how often they use the following technologies on a 5-point scale from "never" to "every day": smartphone; video games; AR; social networks; AR filters on social networks.

Other demographic variables. Lastly, participants were asked to provide demographic information (e.g., age, gender, education) as well as pet ownership (whether they own a pet), vacation preferences (what would be the perfect vacation for them, between sea, forest/mountain, countryside, city or home), glasses (whether they wear glasses), dietary options (whether they are vegetarian).

3.2 Experimental Conditions and Main Questionnaire

We employed a between-subject experimental design with two experimental conditions: *Control* and *AR* treatment. Following the completion of the Pre-Experimental questionnaire, participants in both conditions were provided with a document containing a brief text on the detrimental effects of plastic pollution, along with a call for donations, similar to what one might encounter in real-life situations (see Figure A1 in Appendix A). After reading the text, participants assigned to the *Control* group moved on to the *Main Questionnaire*, while those assigned to the *AR* group were asked to stand up and come to the center of the room. The experimenter set up the mobile AR application "Eco Animals" on the tablet and explained how to use it.

AR Stimuli. The mobile application "Eco Animals" was developed to our specifications by an external developer using the cross-platform game engine Unity. The application was installed on a Samsung Galaxy Tab S5e tablet running the Android

[5]We developed our own scale to ensure that the overall time required to complete the Pre-Experimental Questionnaire was manageable, as the General Ecological Behavior scale by Kaiser and Wilson (2000) and follow-up studies include a minimum of 33 and up to 51 items.

[6]We acknowledge that measuring this variable at the beginning of the experiment, in our Pre-Experimental questionnaire, may have introduced potential experimenter demand effects, by priming our participants around environmental questions. However, since this effect is consistent across all experimental conditions, it does not compromise the validity of our comparative statics.

operating system. The application illustrates the consequences of marine plastic pollution, presented in the AR format, with the visual content taking the form of the five most affected animals (see Figure 2): a sea turtle, a bird, a dolphin, a whale and a seal (Gall and Thompson, 2015). The scenes were inspired by real-life situations and anecdotal evidence.[7] After opening the application, users immediately see the image from the device camera. As soon as the system understands the environment and recognizes the flat surface, a white rectangle appears on the bottom. Upon clicking on it, an animated three-dimensional projection of a life-size animal being strangled with disposable plastic waste appears and merges with the real environment in real time. The projection is interactive – its appearance reacts to the movements of the tablet. The simplified dashboard has a few buttons: arrows (to move to another animal), zoom (to zoom in or out of an animal) and a rotate function (to rotate an animal). Participants in the AR treatment were briefly instructed on how to use the application and then asked to freely interact with it for 2 minutes. The video demonstration is available in the online ResearchBox. The AR stimuli were implicitly validated through semi-structured interviews with nine experts from diverse backgrounds, all with expertise in creating campaigns to raise awareness of environmental issues, promoting pro-environmental behavior, and exploring new tools, trends, and technologies.[8]

Main Questionnaire. The main questionnaire assessed psychological distance, concern about plastic pollution, preparedness to act, and donations to a pro-environmental organization. In the AR treatment only, participants were asked three additional questions about the AR stimuli. Details and questions of the main questionnaire can be found in Table A2 of Appendix A.

Psychological distance (PD). We measured PD using a four-dimension questionnaire based on Spence et al. (2012). Geographical distance was assessed with two questions regarding participants' perceptions of whether plastic pollution affects their

[7]To make the AR intervention as realistic as possible, we sought to replicate images commonly reported in the media of "marine animals entangled in single-use plastics or affected by plastic pollution". This web search yielded images of the same five animals identified by Gall and Thompson (2015). Additionally, we consulted statistics and reports from environmental organizations to better understand the types of plastics that typically end up in the ocean. Based on this research, we identified and sourced 3D models of single-use plastics such as food containers, plastic bags, straws, and other similar items.

[8]The nine experts, based in five different countries (France, Poland, Singapore, Spain, and the US), represented a variety of sectors: the public sector (a marketing manager of an oceanographic museum and a university researcher specializing in VR, UX, and speech recognition); the private sector (three CEOs and a 3D artist and developer from AR and VR agencies); and nonprofit organizations (the founder of an environmental NGO, a consultant for the United Nations Environment Programme, and an urban policy consultant specializing in environmental issues). The individual interviews, each averaging one hour, were conducted between September 2021 and May 2022. Their aim was to evaluate the design of the AR stimuli in terms of its informational, social, and technological aspects. The experts' feedback did not lead to systematic critiques of the design or suggestions for improvements that could be implemented in a laboratory experiment.

Figure 1: Experimental procedure

	1 week before	Day of the experiment (15 to 17 minutes)							1 week after	
Control	Recruitment of participants	Consent form signing, random allocation to treatments	Introduction text	Pre-experimental questionnaire	Text about plastic pollution, donation appeal		Main questionnaire	Show-up fee payment, dismissing	Online lottery (random draw)	Payment & donation
AR	Recruitment of participants	Consent form signing, random allocation to treatments	Introduction text	Pre-experimental questionnaire	Text about plastic pollution, donation appeal	2-minute AR stimuli	Main questionnaire	Show-up fee payment, dismissing	Online lottery (random draw)	Payment & donation

Notes: AR-VR Questionnaire omitted as it was only administered during the Wave 2 study.

local area and distant areas. Social distance was measured with two questions, evaluating whether participants believed plastic pollution primarily affects developing countries and whether it has a significant impact on people similar to them. Temporal distance was assessed with a single question asking when participants thought their country would start experiencing the effects of plastic pollution. Uncertainty about plastic pollution was evaluated with four questions addressing participants' perceptions of its existence, severity, causes, and effects. The responses to the nine items were combined into a single scale (Cronbach's $\alpha = 0.55$). The response options for all PD-related questions (except for temporal distance, which had four) were four- or five-point Likert scales. When necessary, responses were reversed so that higher scores indicated greater PD.

Concern about plastic pollution. Concern about plastic pollution was assessed using four questions adapted from Spence et al. (2012). The first question measured general concern about plastic pollution, while the other three focused on specific concerns regarding: the personal impact of plastic pollution, its impact on society, and its impact on wildlife and animals.

Preparedness to act. We assessed participants' behavioral intentions to engage with the problem of plastic pollution through three questions about their consumption habits, recycling practices, and policy support.

Pro-environmental behavior (Donations). We measured actual donations using an incentivized game. Each participant was endowed with €300 and made a decision on how much to donate to a pro-environmental organization previously chosen from a comprehensive list (see Section 3.1). Participants were given ten donation levels, starting with €0 and ending with €300 (see Table A2 in Appendix A). They were informed that the decisions they made were implemented based on the results of a lottery, which was implemented after each battery of 30 participants. Hence, each participant had a $1/30$ chance of winning. Lotteries and raffles are often used in exper-

Figure 2: Examples of stimuli in the AR treatment

imental economics research and public goods fundraising (Carpenter and Matthews, 2017). Recent work has found that donations in experimental games are not affected by whether all participants receive a payment or some of them are randomly drawn based on a lottery (Charness et al., 2016). In our design, we implemented the decision made in the donation game by the participant who was randomly selected by the lottery. Then, the amount indicated in the game was donated to his/her selected organization, while the remaining amount was given to the participant. After the experiment, participants were notified via email about the lottery, which was recorded on Zoom, and later informed about the donations, including a copy of the transfer receipt. Examples of these receipts are provided in the online ResearchBox.

Self-assessment of AR effect. [Only in the AR treatment] We assessed the effects of the AR stimuli. These three questions asked whether participants felt the presence of animals in the room, had similar experiences in the past, and whether the application made them feel closer to the issue of plastic pollution.

3.3 AR-VR questionnaire

After the Main Questionnaire, participants responded to a final *AR-VR Questionnaire* that measured participants' beliefs on the effect of immersive technologies (AR and VR) on average donations in our donation game (see Section A.1). The questionnaire included two items asking them to estimate, within the set $\{0, 1, , ..., 300\}$, the average donation in the presence of either text only, text combined with AR, or text combined with VR technologies. In particular, participants in the Control treatment read a description of AR and VR technologies, including their definition and use, and were asked their belief about participants' average donation had we implemented either of these technologies in their experiment. Accordingly, participants in the AR treatment read a description of the VR technologies, and were reminded that of the text-based appeal, to then express their belief about average donation in the two no-AR scenarios, i.e., in the presence of text only, and of text combined with VR. Answers to these questions were not incentivized as our design does not allow us to compare expected average donations with actual donations in the presence of VR.

3.4 Sample and procedures

Our laboratory data collection relies on two waves of experimental sessions. In Wave 1, we recruited a total of 86 participants (29 in Control, 57 in AR). In Wave 2, we collected a total of 103 participants (50 in Control, 53 in AR).[9] As a whole, this sample includes 189 students recruited from the same students pool (79 in Control, 110 in AR). Invitations were sent via the university's web-based Online Recruitment System for Economic Experiments (ORSEE) (Greiner, 2015). Table B1 in Appendix B provides the demographic characteristics of this sample (columns Control-Lab and AR-Lab). Data from the AR-VR Questionnaire were collected only for Wave 2.[10]

[9] We thank an anonymous referee for suggesting the increase in sample size through the addition of a second wave of experimental sessions.

[10] We thank an anonymous referee for suggesting the AR-VR comparison.

All sessions were conducted at the Laboratory for Experimental Economics of Université Côte d'Azur (LEEN NiceLab) in the period from June to November 2021, for Wave 1, and October to November 2024 for Wave 2. Wave 1 took place during the last period of COVID-19 restrictions in France: a first sub-wave (Wave 1a) of sessions (59 in total) with either the Control treatment (29 sessions) or the AR treatment (30 sessions) was conducted on June 21-23, 2021. Treatment allocation in Wave 1a was randomized per individual session, with both treatments conducted on all three days. A second sub-wave (Wave 1b) of sessions (27 in total, only for the AR treatment) was conducted on November 25–26, 2021.[11] Section B.1 of Appendix B provides details on the reasons behind the timing of the different waves of experimental sessions.

The procedure followed is identical for both waves. Upon arrival to the laboratory, participants signed an informed consent form, and were given an individual code which was later used in the final lottery. After entering the experimental room, the experimenter read aloud the introductory text, which contained information about the experiment, the rights of the participants, and incentives. Participants were informed that they would be taking part in a decision-making study and that they had an equal chance to win €300 in a lottery and that they could choose to donate a desired amount to an environmental organization of their choice from a predefined list.

To ensure the credibility of the decision task, the draw was conducted via online video streaming a few days after the sessions, recorded, and shared with all participants. Following the draw, the winners were paid, the environmental organizations selected by the winners received the donations, and proof of the donations was emailed to all participants. Proofs of the donations and recordings of the online lottery draws are available in the online ResearchBox.

All tasks of Figure 1 – pre-experimental questionnaire, text about plastic pollution and donation appeal, AR stimuli (in the AR treatment only), main questionnaire, and AR-VR questionnaire (in Wave 2 only) – were performed with the same Samsung Galaxy Tab S5e tablet. All questionnaires were created via Lime Survey and participants completed them in the tablet's internet browser.

The average session duration for Wave 1 of experiments was 15 minutes for the Control group and 17 minutes for the AR treatment group, due to a 2-minute AR stimuli visualization. For Wave 2, session durations increased by 2 minutes because of the inclusion of the final AR-VR Questionnaire.[12] The show-up fee was €7.

The recruitment and experimental design were approved by the Ethical Commit-

[11]In both Waves 1a and 1b, no significant COVID-related difficulties were encountered, except for cleaning the tablet after each session, as all sessions were conducted individually (one participant at a time with one experimenter). Therefore, social distancing was not an issue (indeed, we had one big laboratory room, which in normal conditions was allowed to host up to 40 subjects, available for the participant and the experimenter only – see Figure 2).

[12]We ensured that participants in the AR treatment did not spend significantly more time than those in the Control treatment. Limiting the time allocated for AR visualizations to 2 minutes resulted in an average session duration that was approximately only 10% longer for the AR treatment across all sessions.

tee of Université Côte d'Azur (CERNI) under protocol #2021-030. All participants signed an informed consent form prior to participation. Methods and procedures of Wave 2 of data collection were pre-registered (AsPredicted #194015, see Section B.2 of Appendix B). Our sample size is justified by power analysis to ensure a power of at least 80% for all statistical tests used in our hypotheses testing.

4 Results

We present the results from the laboratory experiment in four steps. First, we test whether our AR intervention shortens participants' psychological distance (H1). Second, we test whether psychological distance mediates the effect of AR onto pro-environmental behavior, measured by donations to environmental organizations (H2). Third, we report the results of the AR intervention on secondary variables of the Main Questionnaire of Section 3.2, i.e., concern about plastic pollution and preparedness to act. Finally, we show the results on participants' expectations about immersive technologies effectiveness in raising donations to environmental organizations (from the AR-VR Questionnaire of Section 3.3).

4.1 The effect of AR on Psychological Distance

Following H1, we expect to observe shorter psychological distance in the AR treatment relative to the Control treatment. However, contrarily to our expectations, the results from our laboratory experiment suggest no substantial difference in PD levels between treatments. Figure 3 depicts the distribution of PD between the Control and the AR treatment. The average PD level in the Control treatment is 1.79, while PD in the AR treatment is 1.88 (Wilcoxon rank sum test, $p = 0.411$). Results are also confirmed when regressing PD on an indicator variable that turns on when the treatment is AR (Table 1, models 1-2). We report no significant difference between treatments in all model specifications. Controlling for other measures, such as age, gender or past use of AR does not affect the main results (Table 1, model 2).

Participants' self-reported environmental engagement score (EES) in the regression model is significant and negatively correlated with PD, highlighting the fact that individuals who are environmentally concerned display shorter psychological distance. Furthermore, participants who reported to have used AR technologies in the past display higher psychological distance.

Figure 3: Distribution of PD scores across treatments.

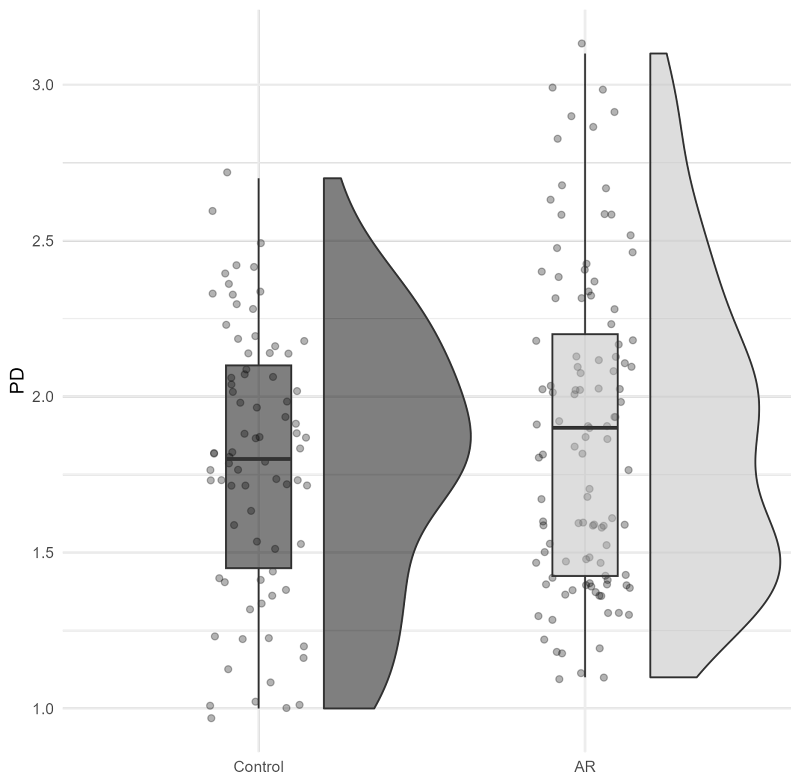


Table 1: Regression models of PD and Donation levels.

	Dependent variable:			
	PD		Donation	
	(1)	(2)	(3)	(4)
AR	0.091	0.105		
	(0.069)	(0.072)		
EES		-0.105^{**}		18.738^{**}
		(0.046)		(7.425)
Age		−0.007		−0.544
		(0.008)		(1.302)
Male		0.021		−8.093
		(0.080)		(12.950)
Use AR		0.116^{**}		−6.821
		(0.045)		(7.308)
Study levels		0.029		−1.253
		(0.054)		(8.685)
Use smartphone		−0.216		−66.314
		(0.471)		(75.512)
Use video games		0.005		6.133
		(0.034)		(5.478)
Use AR filters		−0.036		−0.186
		(0.031)		(4.848)
Donated before		0.020		−0.067
		(0.042)		(6.808)
PD			−13.369	−9.436
			(11.453)	(12.193)
Constant	1.701^{***}	3.007	108.085^{***}	383.585
	(0.114)	(2.363)	(21.805)	(379.890)
Observations	189	183	189	183
R^2	0.009	0.090	0.007	0.069
Adjusted R^2	0.004	0.038	0.002	0.015
Residual Std. Error	0.469	0.459	73.714	73.833
F Statistic	1.743	1.710^{*}	1.363	1.271

Notes: 6 missing responses from the Pre-Experimental Questionnaire. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

4.2 Donation levels and mediation effect of PD

As stated in H2, we aim to test whether AR had an overall effect on donations in the Donation Game and whether such an effect is mediated by PD. Figure 4 shows the distribution of donations to environmental organizations in the two treatments. The average donation amount in the Control treatment is slightly lower (76.8€) than that observed in the AR treatment (88.1€). However, such a difference is not statistically significant (Wilcoxon rank sum test, p=0.19). When assessing the impact of PD on donations, the regression model estimates show no statistical relationship between these variables (Table 1, models 3-4). These results are not surprising considering that AR has no impact on PD, as explained in the previous section. As expected, participants' self-reported environmental engagement score (EES) has a positive effect on donations (model 4).

From a first analysis of the data it seems that donation levels do not differ across treatments, and that they are not significantly correlated with PD. To thoroughly assess our second hypothesis, we run a mediation analysis to jointly estimate the effect of AR on PD and, in turn, the mediating effect of PD on donations.[13] In all mediation models, we account for a set of controls previously included in our analyses, that is, demographics, past use of AR, and EES. Our technique is based on the bootstrap method described in Preacher and Hayes (2008) which is often preferred, especially with small samples, to other approaches due to its convenience in not assuming that the data is normally distributed.

Results from the mediation analysis are reported in Figure 5. They show no evidence of a mediating effect of PD on donations. The indicator variable AR has no significant effect on PD, as shown in the previous section ($a = 0.11$, $p = 0.14$), and it has no significant effect on donations directly ($c = 12.47$, $p = 0.26$). The mediator variable, PD, has no significant effect on donations ($b = -10.90$, $p = 0.37$), leading to a non-significant mediation effect (Indirect effect $= -1.19$, $p = 0.46$). Lastly, when regressing donations on AR alone, without the inclusion of PD, its effect is not significant (Total effect $= 11.32$, $p = 0.30$). Considered together, our analyses suggest insufficient evidence in support of a mediation role of PD.

[13]We used the package *mediator* available from CRAN.

Figure 4: Donation levels by treatment.

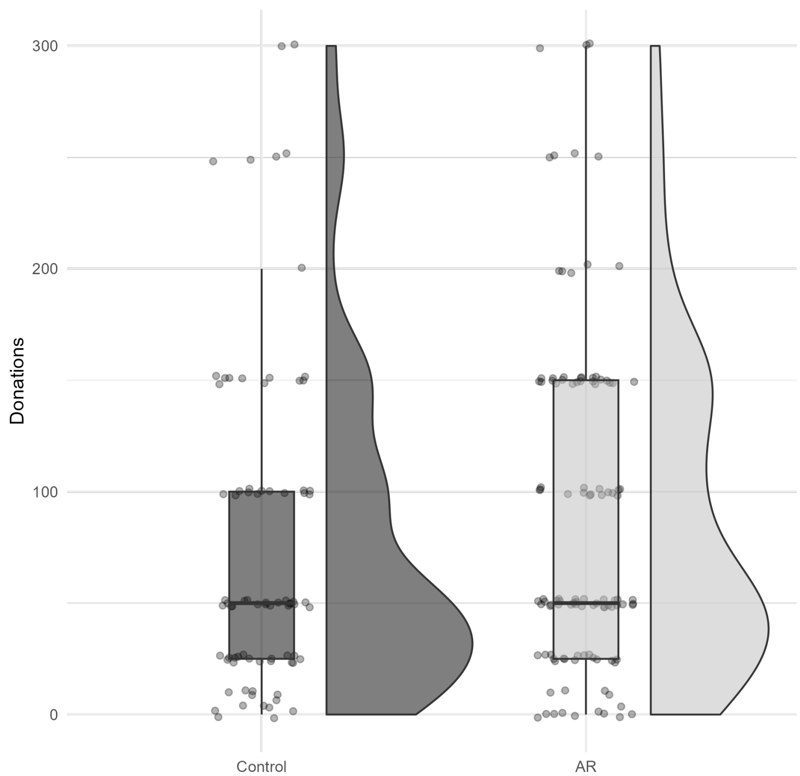
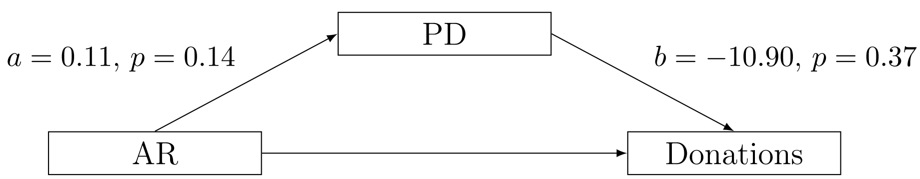


Figure 5: Results from the mediation analysis.



Direct effect, $c = 12.47$, $p = 0.26$

Indirect effect $= a \cdot b = -1.19$, $p = 0.46$

Total effect = Indirect + Direct $= 11.32$, $p = 0.30$

4.3 Self-Reported Concern and Preparedness to Act

Although AR has not impacted the behavior of participants in our experiment, immersive technologies may have the potential to affect the urge to act in favor of the environment and to raise concern. In this section, we examine the impact of the AR intervention on self-reported measures of concern about plastic pollution and preparedness to act. These measures were elicited in the Main Questionnaire and included four questions on concern about plastic pollution, and three questions about participants' preparedness to act, including plastic consumption habits, recycling practices and policy support (see Section 3.2).

Figure 6 depicts the distribution of these items across the Control and AR treatment. Overall, we find no significant differences in all these measures. Items reflecting participants' self-reported concern about plastic pollution are statistically indistinguishable between treatments (Wilcoxon rank sum test, all $p > 0.10$). We do not report any significant difference between treatments when comparing participants' preparedness to act (Wilcoxon rank sum test, all $p > 0.10$). Controlling for individual characteristics using regression models does not affect the results, showing no statistically significant difference across treatments (see Tables C1-C2)

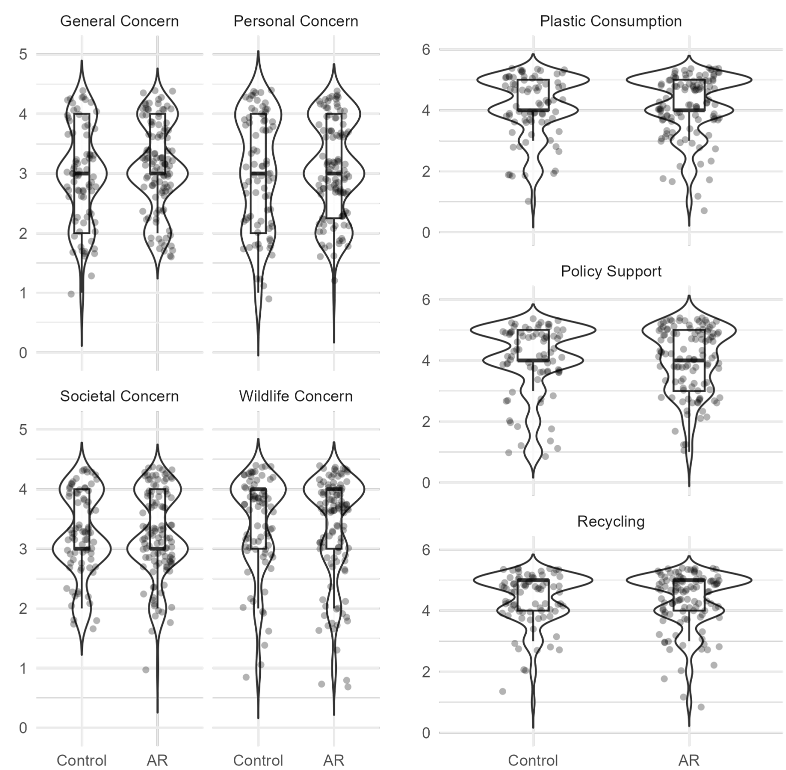
4.4 AR and VR Expected Donations

We now examine participants' opinions on whether immersive technologies (i.e., AR and VR) are thought to outperform simple text-based appeals in raising donations. While our experimental results show no significant effect of AR on donations, it is important to understand people's expectations about the potential of immersive technologies like AR and VR. Understanding expected treatment effects might be useful since perceptions of effectiveness shape public policies, even if those perceptions are not aligned with actual outcomes. In the context of environmental campaigns, policymakers and organizations rely on the belief that new technologies will motivate action. If the public expects AR to be effective, they may be more inclined to engage with such interventions, even if they do not directly lead to behavior change. Our focus here is on the final AR-VR Questionnaire (Section 3.3) we have administered in both the Control and AR treatments, to participants in Wave 2 of data collection.

Our main variable of interest is the expected difference in average donation levels in our Donation Game under the presence of simple text-based message or when combining them with either immersive technologies.

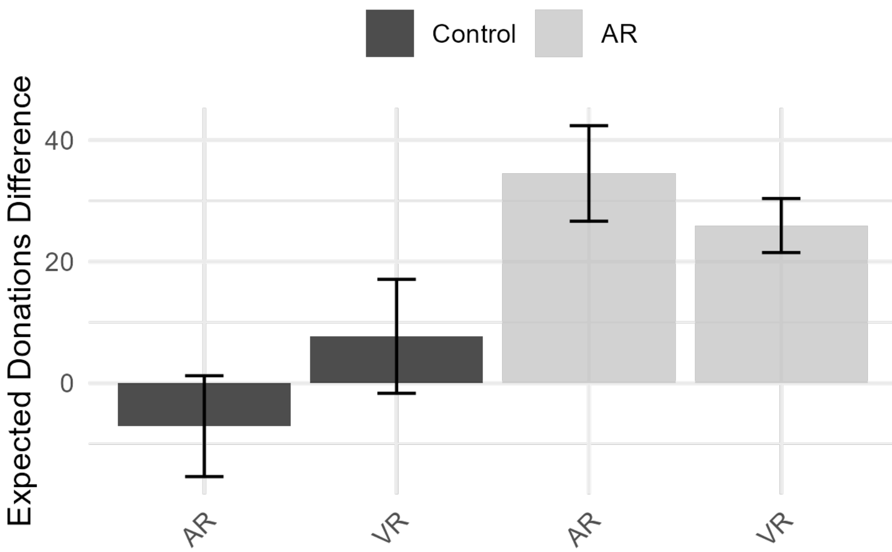
In the AR-VR Questionnaire, we elicited the expected average donation under three scenarios: only text-based appeals (i), and text-based appeals combined with either AR (ii) or VR (iii). Expectations for scenarios (ii) and (iii) were elicited in the Control treatment, where participants were informed of the average donation level indicated by participants in previous sessions of the same (Control) treatment, which is a proxy of (i). Similarly, expectations for scenarios (i) and (iii) were elicited in the AR treatment, where participants were informed of the average donation level

Figure 6: Distribution of self-reported measures of plastic pollution concerns and preparedness to act, by treatment.



Notes: Panels on the left include self-reported measures of plastic pollution concerns (general, personal, societal, and wildlife). Right panels report self-reported measures of preparedness to act (plastic consumption habits, policy support, and recycling practices).

Figure 7: Difference in expected average donations relative to text-based appeals across treatments (Control and AR).



Notes: The bars represent the difference between expected donations in AR or VR scenarios following text-based appeals and expected donations from text-based appeals alone. The whiskers report the 95% confidence intervals.

indicated by participants in previous sessions of the same (AR) treatment, which is a proxy of (ii). In both treatments, by subtracting (i) from (ii), we calculate the expected treatment effect of AR. By subtracting (i) from (iii), we calculate the expected treatment effect of VR. By substracting (ii) from (iii), we determine the expected incremental effect of VR on AR intervention.

Pooling the data from the Control and the AR treatments, we find that participants expect that AR and VR help increase average donations to environmental organizations. Specifically, given the set $\{0, 1, ..., 300\}$ euros, participants expect that AR and VR significantly help raise extra average donations respectively by 14.32€ and 17.08€ (Wilcoxon test, $p = 0.007$ and $p = 0.003$). We report no significant difference in the expected average donations between AR and VR (Wilcoxon test, $p = 0.74$).

Because participants' perceptions may be influenced by their firsthand experience with immersive technologies during our experimental sessions, we analyze expectations from the Control and AR treatments separately. Participants in the AR treatment had experienced AR immersive technology prior to completing the AR-VR Questionnaire. Figure 7 reports the differences in expected average donations relative to text-based appeals, when combining them with AR or VR technologies.

Participants in the Control treatment expected average donations under AR to be slightly lower (€7.1) than those under text-based appeals alone, although the difference is not statistically significant (Wilcoxon test, $p = 0.369$). Similarly, VR is expected to solicit slightly higher average donations (€7.7) compared to text-based appeals, but this difference is also not statistically significant (Wilcoxon test, $p = 0.589$). However, because participants expect these technologies to have opposite directional effects relative to text-based appeals, VR technologies are expected to generate significantly higher average donations compared to AR (€14.8, Wilcoxon test, $p = 0.007$).

Participants assigned to the AR treatment expect instead that both immersive technologies outperforms text-based appeals alone in raising donations. Expected average donations in the AR and VR scenarios are, respectively, 34.53€ and 25.94€ higher than under text appeals alone (Wilcoxon test, $p < 0.001$ in both cases). The difference in expected donations between AR and VR is not statistically different from zero (Wilcoxon test, $p = 0.118$).

Overall, participants' perceptions of the effectiveness of immersive technologies in raising donations are positive and supportive. Firsthand experience with AR likely amplified participants' sense of the technology's potential impact, influencing their expectations about its ability to drive donations. This effect holds regardless of the type of immersive technology that might be used, whether AR or VR.

4.5 Robustness checks: AR intervention contextualized

The results of a qualitative study assessing the feedback on the design and performance of our AR laboratory treatment indicated that the lack of visual fidelity could be a barrier to the effectiveness of AR interventions (Buljat, 2022a). Participants stated that it was unusual for them to see sea animals on the floor of the classroom. Therefore, it is reasonable to assume that the overall impression of an AR experience depends on its visual fidelity and the context in which an AR intervention is experienced. To address this issue, we decided to switch from the context-free laboratory setting to a context closer to the natural habitat of marine animals and replicate the AR treatment on the beach, where the AR experience might appear more natural and realistic. Therefore, in a follow-up contextualized experiment, we investigated whether the results observed in the AR-Lab treatment would differ when the same AR stimuli were implemented in a more realistic context (namely, AR-Context). Methods and procedures of this contextualized study were pre-registered (AsPredicted #107359, see Section B.2 of Appendix B).

4.5.1 Methods and Sample

The contextualized sessions (AR-Context) were conducted on a beach close to the location of the laboratory of the original study (Villefranche-sur-Mer, south of France), in late September 2022. The protocol was the same as the one used to conduct the

AR treatment in the laboratory study. The only difference was that the AR visualization of marine animals entangled in single-use plastics was contextualized on the beach (see Figures A2, A3 in the Appendix for the experimental setup).

The contextualized study lasted two full days, during which an experimenter and two protocol-trained assistants guided participants through 73 individual sessions. Participants first arrived at the registration desk to sign a consent form. They were then seated at a table and asked to complete the pre-questionnaire on a tablet. After completing the pre-experimental questionnaire, they were instructed to stand and walk to a nearby beach (approximately 15 meters away). There, the experimenter explained how to use the AR application on the tablet and asked them to interact with it for 2 minutes. After the AR stimuli, participants returned to the table to complete the main questionnaire on the tablet. Before leaving, they received the same €7 show-up fee as in the laboratory study, as well as information about the online recording of the random draw used to determine the lottery winners.

We recruited a total of 73 subjects from the same population as in the laboratory study, described in Section 3.4. Recruitment was done through ORSEE and we ensured that subjects had not previously participated in a similar experiment. Our sample compositions are comparable across studies (see Table B1 for the demographic characteristics). In AR-Context we collected the same independent and control variables as in AR-Lab. The validity of the compound measures of AR-Context is comparable to AR-lab (PD – Cronbach's $\alpha = 0.45$, EES – Cronbach's $\alpha = 0.71$).

4.5.2 Results

We first investigate whether PD levels after AR stimuli in the contextualized study differ from those measured in the laboratory (H1). Figure C1 of Appendix C reports the distribution of PD scores across AR-Lab and AR-Context. Average psychological distance in AR-Context is 1.76, and statistically undistinguishable from the average PD measured in AR-Lab (pairwise Wilcoxon test, Bonferroni correction, $p = 0.32$). Results from regression models (see Table C3, model 1) report no statistical difference between contextualized and laboratory measures. The association between EES and PD remains negative.

When analyzing decisions in the Donation game (H2), average donation levels in AR-Context are statistically comparable to those observed in AR-Lab (108€, pairwise Wilcoxon test, Bonferroni correction, all $p > 0.10$; see also Figure C2). We report no statistical difference between AR-Context and AR-Lab also when regressing donation levels controlling for individual characteristics (Table C3, model 2).

Overall, the contextualized experiment replicates results seen in the laboratory experiment, i.e., no significant impact of the AR stimuli comparded to the Control-Lab. More specifically, PD levels do not differ between laboratory and field environment under the presence of AR. Donation levels do not differ across treatments and seem not to be affected by one's perception of AR.

5 Discussion and Concluding Remarks

In this work, we provide first causal evidence on how AR visualizations depicting the consequences of plastic pollution on marine wildlife affect pro-environmental behavior and participants' sense of urgency to act. By leveraging upon Construal Level Theory (CLT) (Trope and Liberman, 2010), we tested whether psychological distance (Spence et al., 2012) is a main barrier that hinders pro-environmental behavior. We ran a laboratory and a contextualized experiment with university students recruited from a large campus in France. We measured participants' psychological distance from environmental issues and *actual* donations to pro-environmental organizations.

Contrary to our experimental hypotheses, the results from both experiments provide no evidence that AR reduces psychological distance or increases pro-environmental behavior. We also examined whether AR visualizations influence individuals' preparedness to act in favor of the environment, environmental concern, or support for environmental policies. Consistent with our primary behavioral findings, there were no significant changes in any of these measures. Taken together, our experimental results suggest a pessimistic outlook on the effectiveness of AR as a tool to promote pro-environmental behavior.

Lastly, we investigate a compelling question: What do individuals expect about the effectiveness of immersive technologies? We address this question by eliciting participants' *expected* donations to pro-environmental organizations, which allowed us to estimate the relative advantage of AR and VR to text-based appeals. Our results are twofold. First, there is a general optimism around VR technologies, which are perceived as more effective at promoting pro-environmental behavior compared to text appeals. Second, while participants initially hold realistic expectations about AR – recognizing it as no more effective than text-based appeals – this changes after they directly interact with the technology. Following firsthand experience during our experiment, they become overly optimistic about the potential of AR, likely influenced by the novelty effect of the technology.

What could explain our AR ineffectiveness? One possibility is that exposure to AR visualizations (two minutes) was too brief to significantly influence donation decisions. This is an interesting question that could be empirically addressed by introducing different experimental stimuli and varying the length of exposure. Another potential reason is that the AR visualizations may not have been realistic enough. Under this hypothesis, participants might have not felt a stronger connection to marine plastic pollution due to a lack of perceived presence of the represented animals. However, responses to our final questionnaire show highly positive feedback to questions asking whether our AR visualizations brought participants closer to the problem of plastic pollution and whether they felt the realistic presence of animals in the experimental room. Furthermore, evidence from our contextualized experiment (on the beach) suggests that the reported null effect is not entirely due to the lack of presence.

With this, our findings on the perceived effectiveness of AR highlight a critical issue: the gap between public attitudes and actual outcomes can significantly influence policy decisions. Public perceptions of a policy's effectiveness often play a crucial role in its adoption and implementation, even when these perceptions are misaligned with its actual impact. This is particularly relevant as policymakers and organizations increasingly assume that immersive technologies, such as AR, will effectively drive behavioral change. If the public perceives AR as a highly effective tool, they may be more inclined to support and engage with these interventions, regardless of whether they produce tangible impact on pro-environmental behaviors.

Although exploratory, our evidence on the optimism surrounding the use of AR for environmental purposes is novel. Notably, our data indicate that this optimism is significantly amplified when individuals experience these technologies firsthand. This effect may be attributed to a "novelty effect", where exposure to new and engaging tools enhances positive perceptions. For instance, prior research suggests a tendency toward excessive optimism when making decisions involving new technologies (Clark et al., 2016). Alternatively, this effect could arise from the fact that direct interaction with the technology fosters a better understanding of its functionality. Indeed, prior studies highlight that familiarity and comprehension are critical factors in strengthening support for environmental policies (Dechezleprêtre et al., 2022).

We believe there is considerable potential for future research in this area. AR visualizations could be more effective in contexts different from the one we considered (e.g., promoting plastic waste recycling). Another open question is whether AR is more effective than 2D videos (without AR features). Our experiment, which found no difference between the two extreme cases of text-based appeals and AR, suggests that any difference between AR and 2D videos, if it exists, would likely be minimal. Previous literature has explored this question, with some studies reporting null results (Dunn et al., 2021) and others finding significant impacts on pro-environmental behavior (Levstek et al., 2024). However, unlike our study, these investigations relied on self-reported measures. Overall, more evidence is needed to address this gap.

An important open question that should be addressed is whether the positive effects commonly observed in AR and VR research are driven by these visualizations reducing psychological distance and making environmental issues feel more immediate, or merely by the novelty and excitement of using these technologies.

Another significant challenge in understanding the effectiveness of immersive technology interventions lies in the overwhelming abundance of information about environmental threats. Within the framework of bounded rationality, an excess of information can reduce the perceived value of additional data. This phenomenon is particularly relevant in developed countries, such as the one where this study was conducted. In contrast, AR interventions may have a greater impact in countries where awareness and sensitization about environmental issues are relatively low.

Future research should further explore these factors, focusing on both the psychological mechanisms underlying AR interventions and the contextual differences that may influence their effectiveness.

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Appendix A: Experimental material

Table A1: Pre-questionnaire items

Variable	Questions	Answer options
EES	I consider myself to be an eco-responsible person.	5-points Likert-scale
	I generally feel concerned about environmental issues.	5-points Likert-scale
	Whenever I can, I choose eco-responsible products.	5-points Likert-scale
	Whenever I can, I recycle the waste.	5-points Likert-scale
Past donation	Have you ever donated money to an environmental organization?	5-points scale
Organisation	To which of these organizations would you be willing to donate money?	4Ocean Colibris 06 Nice Fondation Prince Albert II de Monaco Greenpeace, National Geographics Parley Plastic Pollution Coalition Surfrider The Ocean Cleanup The Sea Cleaners World Wildlife Fund (WWF) Zero Waste France
Frequency smartphone	Please indicate how often do you use smartphone.	5-points scale
Frequency video games	Please indicate how often do you use videogames.	5-points scale
Frequency AR	Please indicate how often do you use augmented reality.	5-points scale
Frequency social networks	Please indicate how often do you social networks.	5-points scale
Frequency AR filters	Please indicate how often do you use augmented reality filters on social networks.	5-points scale
Age	age	Short answer
Gender	gender	Male / Female
Study level	Last diploma	Without study Primary school / college Secondary school with the bac Bachelor Master Doctorate Other
Study field	Field of study?	Short answer
Pet	Do you have a pet?	Yes / No
Vacation preferences	For you, perfect vacation is...	in forest / mountain at the sea in the city in the countryside at home other
Glasses	Do you wear glasses?	Yes, regularly Yes, sometimes No, never
Vegetarian	Are you vegetarian	Yes (I don't eat meat or fish) Yes (but I eat fish) No

Figure A1: Text about plastic pollution

Every year, millions of tons of plastic are dumped into the oceans. If no action is taken, the impact of plastics on our ecosystems, our health and our economies will become increasingly serious. We need to address the full scope of the problem by stopping the production of plastics in the first place and cleaning our oceans of non-degradable plastic waste. Your donation will help us take action for a planet free of plastic pollution.

Table A2: Main questionnaire

Variable	Questions
Geographic distance	My local area is likely to be affected by plastic pollution.
	Plastic pollution will mainly affect areas far from here.
Social distance	Plastic pollution will mainly affect developing countries.
	Plastic pollution is likely to have a big impact on people like me.
Temporal distance	When, if at all, do you think France will start to feel the effects of plastic pollution?
Uncertainty/scepticism	Plastic pollution is a completely natural process and is not caused by human activities
	I'm uncertain that plastic pollution is really happening.
	The seriousness of plastic pollution is exaggerated.
	Most scientists agree that humans are causing plastic pollution
Concern about plastic pollution	How concerned are you by plastic pollution?
	Considering any potential effects of plastic pollution which there might be on you personally, how concerned are you with plastic pollution?
	Considering any potential effects of plastic pollution which there might be on society in general, how concerned are you with plastic pollution?
	Considering any potential effects of plastic pollution which there might be on marine wildlife and animals, how concerned are you with plastic pollution?
Preparedness to act	*Plastic Consumption*: I am prepared to greatly reduce my plastic consumption to help solve the problem of plastic pollution
	Recycling I am prepared to greatly improve my recycling habits to help solve the problem of plastic pollution.
	Policy Support: I am prepared to support stricter environmental policies to help solve the problem of plastic pollution.
Donation	You have a chance to win 300 € in a lottery. If you are the winner, how much would you be willing to give to the pro-environmental organization of your choice (chosen during the pre-questionnaire)?
Presence	*(Only for AR)* I felt the presence of animals in the room.
Perceived AR effect	*(Only for AR)* The augmented reality experience brought me closer to the problem of plastic pollution.
Had similar experience	*(Only for AR)* Have you ever had a similar experience with augmented reality?

Note: All variables are measured using a 4 or 5-points Likert scale (Strongly agree – Strongly disagree) except for the question on temporal PD where there is 7-points scale from "never" to "we are already feeling the effects", and for the question on Donation where participants are asked to select one of ten options in the set {0, 5, 10, 25, 50, 100, 150, 200, 250, 300} euros.

A.1: AR-VR Questionnaire

Here we report the items included in the *AR-VR Questionnaire*. The questionnaire contained two items asking participants to estimate, within the set $\{0, 1, ..., 300\}$ euros, the average donation to the environmental organizations under three scenarios: text only, text combined with AR, or text combined with VR technologies.

Items included in the questionnaire, administered in random order, at the end of the **Control treatment** (Control-Lab) of Wave 2:

- **AR**: Augmented Reality (AR) superimposes digital objects onto the real environment. It extends the user's reality by adding virtual and interactive elements to the existing environment. For example, with AR, you could see virtual animals or objects projected into a real environment via a device such as a smartphone or AR glasses. In your case, you read and listened to a text about marine pollution, appealing for a donation. If we had used AR technology, in addition to the text, to show participants in this experiment the consequences of marine pollution, what do you think the average level of donation would be? Please indicate below your estimate of the average level of donation if we had used AR technology to show the consequences of marine pollution. For information, the average donation level of participants who took part to the experiment under the same conditions as you in the past was 100€. Please enter a whole number between 0€ and 300€.
- **VR**: Virtual Reality (VR) transports the user into a fully simulated environment, blocking out the physical world. Wearing a VR headset, users experience an entirely virtual space, often designed to be immersive and in 3D. VR usually requires specialized headsets (such as the Oculus Rift or HTC Vive), which fully cover the user's vision, creating a 360-degree virtual environment. In your case, you read and listened to a text about marine pollution, appealing for a donation. If we had used VR technology, in addition to the text, to show participants in this experiment the consequences of marine pollution, what do you think the average level of donation would be? Please indicate below your estimate of the average level of donation if we had used VR technology to show the consequences of marine pollution. For information, the average donation level of participants who took part to the experiment under the same conditions as you in the past was 100€. Please enter a whole number between 0€ and 300€.

Items included in the questionnaire, administered in random order, at the end of the **AR treatment** (AR-Lab) of Wave 2:

- **Text**: Before taking part in the simulation using Augmented Reality (AR) technology, we read aloud to you a text warning of the consequences of plastic pollution in the oceans. If we had only used the text to show the participants in this experiment the consequences of marine pollution, what do you think the average level of donation would be? Please indicate below your estimate of the average level of donation if we had used only the text to show the consequences of marine pollution. For information, the average donation level of participants who took part to the experiment under the same conditions as you in the past was 93€. Please enter a whole number between 0€ and 300€.

- **VR**: Virtual Reality (VR) transports the user into a fully simulated environment, blocking out the physical world. Wearing a VR headset, users experience an entirely virtual space, often designed to be immersive and in 3D. VR usually requires specialized headsets (such as the Oculus Rift or HTC Vive), which fully cover the user's vision, creating a 360-degree virtual environment. In your case, you were confronted with an experience using Augmented Reality (AR) technology. If we had used VR technology instead of AR, to show the consequences of marine pollution, what do you think the average level of donation would be? Please indicate below your estimate of the average level of donation if we had used VR technology to show the consequences of marine pollution. For information, the average donation level of participants who took part to the experiment under the same conditions as you in the past was 93€. Please enter a whole number between 0€ and 300€.

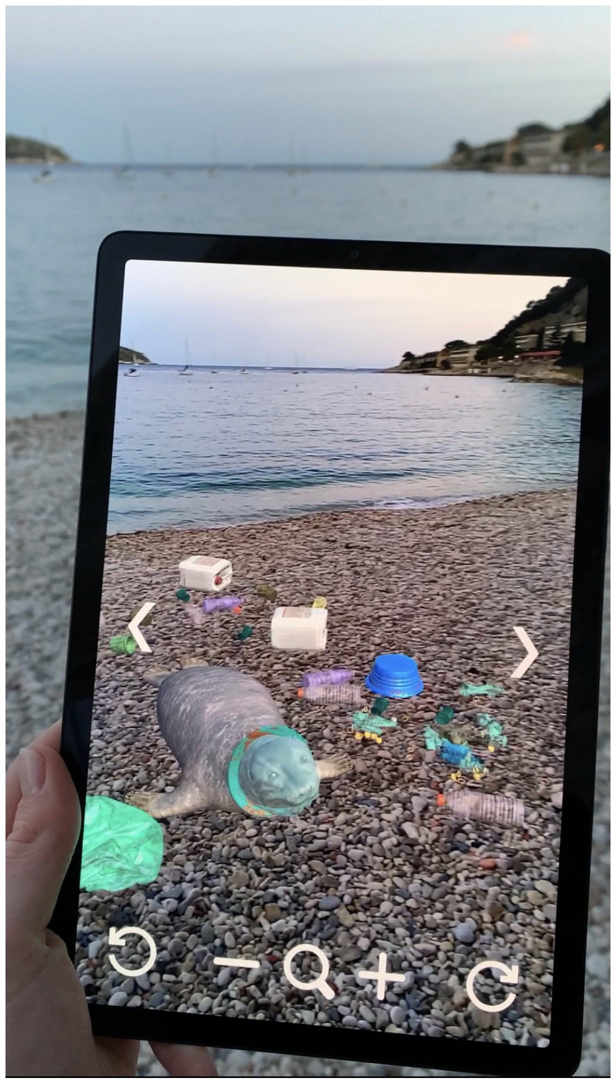

Figure A2: Example of AR visualization in the contextualized study.

Figure A3: Contextualized setup.

Appendix B: Samples, Pre-registrations and Power Analyses

B.1: Samples

Table B1: Samples' socio-demographic characteristics

		Control-Lab	AR-Lab	AR-Context	Total	P-value
Total Participants		**79**	**110**	**73**	**262**	
Gender	Male	38	53	36	127	0.94
	Female	40	55	37	132	
Education	Bachelor degree	44	40	16	100	0.11
	Master degree	21	44	14	79	
	Other	13	22	43	78	
Age		22.1	22.4	26.01	23.32	0.59
EES		3.42	3.45	3.67	3.50	0.07
Frequency Use of AR		1.68	1.69	1.69	1.77	0.87

Notes: Column *P-value* reports the p-value from a non-parametric Kruskal-Wallis test. 5 missing responses across gender and education during Pre-Experimental Questionnaire.

Relying on the first raw of Table B1, we break down the samples based on whether participants took part in the laboratory experiment or its contextualized version, and the period during which they participated in the experiment:

- **Laboratory sessions (Section 3.4)**:

  1. **Wave 1**:
     (a) **Wave 1a**: July 21-23, 2021; 58 subjects (29 Control-Lab, 29 AR-Lab); treatment allocation random per individual session with both treatments run in each day.
     (b) **Wave 1b**: November 21-23, 2021; 27 subjects (27 AR-Lab).
  2. **Wave 2**: October-November 2024; 103 subjects (50 Control, 53 AR-Lab); treatment allocation random per individual session with both treatments run in each day.

- **Contextualized sessions (Section 4.5)**: September 20-21, 2022; 73 subjects (AR-Context).

Laboratory sessions. The primary reason we began our sessions at the LEEN NiceLab (Université Côte d'Azur, Nice) at the end of June 2021 was that France was in a phase of progressively easing social distancing measures introduced to combat the COVID-19 pandemic. Specifically, June 21, 2021 – the first day of Wave 1a – marked the complete lifting of the curfew. Additionally, public events were allowed to resume, albeit with restrictions on the number of participants, mask-wearing, and social distancing. We considered this the first period in which the impact of COVID-19 measures on our results would be negligible.

Following Wave 1a, we recognized that our sample was underpowered. However, we chose to delay conducting additional sessions, anticipating – based on the circumstances at the time – the imminent lifting of remaining social distancing measures. Unfortunately, in November 2021, due to a rise in COVID-19 cases, the French government reintroduced stricter social distancing measures. These included requiring a health pass (certifying full vaccination, a recent negative test, or recovery from COVID-19) to access indoor public spaces, including universities. Consequently, we conducted Wave 1b exclusively for the AR treatment, as it could not be implemented under new curfew restrictions. In contrast, the Control treatment could have been adapted for online implementation. With Wave 2 (conducted in October-November 2024), we ensured sufficient statistical power for all laboratory experiments by increasing the sample sizes for the Control treatment (+50 subjects) and the AR treatment (+53 subjects). This resulted in a total of 79 subjects in the Control-Lab treatment and 110 in the AR-Lab treatment, both exceeding the threshold of 73 participants indicated by our power analysis (see Section B.2). Although the final number of subjects in the AR-Lab treatment was higher, the number of participants recruited after the end of COVID-19 restrictions was similar across the two treatments.

Contextualized sessions. They were conducted over two consecutive days (September 20–21, 2022) on a beach of one of the closest locations to the LEEN NiceLab (Villefranche-sur-Mer). Being on the beach, there were essentially no constraints, particularly since COVID-19-related restrictions had been lifted in France (the French Parliament approved a law ending exceptional anti-COVID-19 measures on August 1, 2022).

B.2: Pre-registrations and Power Analyses

Wave 1 of laboratory sessions (June-November 2021) was not pre-registered as it was initiated before pre-registration became a standard in the experimental field or was explicitly recommended.

Based on insights gained from this initial wave, we pre-registered the contextualized sessions of September 2022 (AsPredicted #107359) to ensure transparency and robust hypothesis testing. Under the same experimental hypotheses H1 and H2 of Section 2.2, we also pre-registered Wave 2 of laboratory sessions of October-November 2024 (AsPredicted #194015). Both pre-registrations are available at ResearchBox.

Laboratory sessions. The treatment comparison concerns Control-Lab vs. AR-Lab. The choice of the sample size we needed to obtain for the laboratory sessions is guided by several power analyses for all our variables of interest and additional analyses. The final sample we collected in Waves 1 and 2 ($N = 189$, 79 in Control-Lab and 110 in AR-Lab) ensures us enough statistical power to draw sound conclusions. More specifically:

- for the main variables of interest (Psychological Distance and Donations), we have calculated the required sample size to be able to detect at least a Cohen's $d = 0.45$ (i.e., small-to-medium effect size; Cohen (1992)) which is the effect size found in previous research (see, e.g., meta-analysis by Nelson et al., 2020; Brambilla et al., 2024). The required sample size we calculated (assuming a power = 0.80, significance level = 0.05, using a two-sided t-test) is of 146 subjects overall (73 observations per treatment).

- for our mediation analysis, we have calculated the required sample size to be able to detect a small-to-medium effect size. We followed the Monte-Carlo method described in Fritz and MacKinnon (2007), relying on the bias-corrected bootstrap method (the one used in our mediation model reported in Figure 5). By setting a small-to-medium mediation effect (see Fritz and MacKinnon, 2007, Table 3, column HH), the required sample size is at least of 148 participants in total across treatments (74 subjects per treatment).

Contextualized sessions. The treatment comparison concerns AR-Lab vs. AR-Context. Under essentially the same experimental hypotheses H1 and H2 of Section 2.2 for the laboratory study, the required sample size for the main variables of interest (Psychological Distance and Donations) is 73 subjects per treatment. Table B.1 shows that this threshold was satisfied, with $N = 183$: 110 subjects in AR-Lab and 73 subjects in AR-Context.

Appendix C: Additional Tables and Figures

Table C1: Regression models of self-reported concern items.

	Dependent variable:			
	General Concern	Personal Concern	Societal Concern	Wildlife Concern
	(1)	(2)	(3)	(4)
AR	0.188*	0.111	0.055	−0.040
	(0.101)	(0.129)	(0.101)	(0.124)
PD	−0.345***	−0.484***	−0.313***	−0.347***
	(0.107)	(0.137)	(0.107)	(0.131)
EES	0.386***	0.122	0.292***	0.233***
	(0.065)	(0.083)	(0.065)	(0.080)
Age	−0.014	0.002	−0.004	−0.020
	(0.011)	(0.015)	(0.011)	(0.014)
Male	0.119	0.170	0.152	−0.091
	(0.113)	(0.144)	(0.113)	(0.138)
Use AR	−0.031	−0.0002	−0.004	−0.196**
	(0.064)	(0.082)	(0.064)	(0.079)
Study levels	0.038	0.049	0.089	0.144
	(0.077)	(0.098)	(0.076)	(0.094)
Use smartphone	−0.534	−0.862	−0.547	−0.765
	(0.662)	(0.845)	(0.660)	(0.811)
Use video games	−0.145***	−0.087	−0.095**	0.006
	(0.048)	(0.061)	(0.048)	(0.059)
Use AR filters	−0.025	−0.001	−0.029	0.045
	(0.043)	(0.055)	(0.043)	(0.053)
Donated before	0.069	0.058	0.009	0.033
	(0.060)	(0.076)	(0.059)	(0.073)
Constant	5.281	7.519*	5.471	7.218*
	(3.336)	(4.258)	(3.327)	(4.084)
Observations	183	183	183	183
R^2	0.311	0.119	0.208	0.161
Adjusted R^2	0.267	0.062	0.157	0.107
Residual Std. Error (df = 171)	0.645	0.823	0.643	0.789
F Statistic (df = 11; 171)	7.026***	2.096**	4.079***	2.981***

Note: *p<0.1; **p<0.05; ***p<0.01

Table C2: Regression models of preparedness to act items.

	Dependent variable:		
	Policy Support	Plastic consumption	Recycling
	(1)	(2)	(3)
AR	0.012	0.093	−0.002
	(0.159)	(0.136)	(0.121)
PD	−0.522***	−0.423***	−0.221*
	(0.168)	(0.144)	(0.128)
EES	0.398***	0.506***	0.485***
	(0.102)	(0.087)	(0.078)
Age	−0.015	−0.003	0.001
	(0.018)	(0.015)	(0.014)
Male	−0.280	0.004	0.045
	(0.177)	(0.152)	(0.135)
Use AR	0.020	0.023	−0.055
	(0.101)	(0.086)	(0.077)
Study levels	−0.040	−0.097	0.027
	(0.120)	(0.103)	(0.092)
Use smartphone	−0.966	−0.449	−0.351
	(1.036)	(0.888)	(0.791)
Use video games	0.010	−0.072	−0.054
	(0.075)	(0.065)	(0.058)
Use AR filters	−0.011	−0.074	−0.032
	(0.068)	(0.058)	(0.052)
Donated before	0.079	0.013	−0.091
	(0.093)	(0.080)	(0.071)
Constant	8.907*	6.054	5.150
	(5.221)	(4.474)	(3.986)
Observations	183	183	183
R^2	0.200	0.272	0.248
Adjusted R^2	0.149	0.225	0.200
Residual Std. Error (df = 171)	1.009	0.865	0.770
F Statistic (df = 11; 171)	3.896***	5.814***	5.127***
Note:			*p<0.1; **p<0.05; ***p<0.01

Table C3: Regression models using data from both laboratory and contextualized sessions.

	Dependent variable:	
	PD	Donation
	(1)	(2)
Control-Lab	−0.032	−17.388
	(0.075)	(12.842)
AR-Lab	0.081	−1.104
	(0.070)	(12.055)
PD		-25.702^{**}
		(11.029)
EES	-0.169^{***}	21.748^{***}
	(0.037)	(6.715)
Age	−0.006	2.670^{***}
	(0.005)	(0.859)
Male	−0.004	3.941
	(0.067)	(11.463)
Use AR	0.105^{***}	−1.476
	(0.038)	(6.593)
Study levels	0.001	−6.527
	(0.042)	(7.170)
Use smartphone	-0.693^{**}	−16.371
	(0.317)	(55.215)
Use video games	0.004	3.681
	(0.028)	(4.889)
Use AR filters	-0.047^{*}	−5.687
	(0.026)	(4.429)
Donated before	0.018	0.632
	(0.034)	(5.802)
Constant	5.875^{***}	113.955
	(1.600)	(283.120)
Observations	256	256
R^2	0.152	0.190
Adjusted R^2	0.114	0.150
Residual Std. Error	0.440 (df = 244)	75.848 (df = 243)
F Statistic	3.979^{***} (df = 11; 244)	4.737^{***} (df = 12; 243)
Note:		$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Figure C1: Distribution of PD scores in the AR-Lab and AR-Context

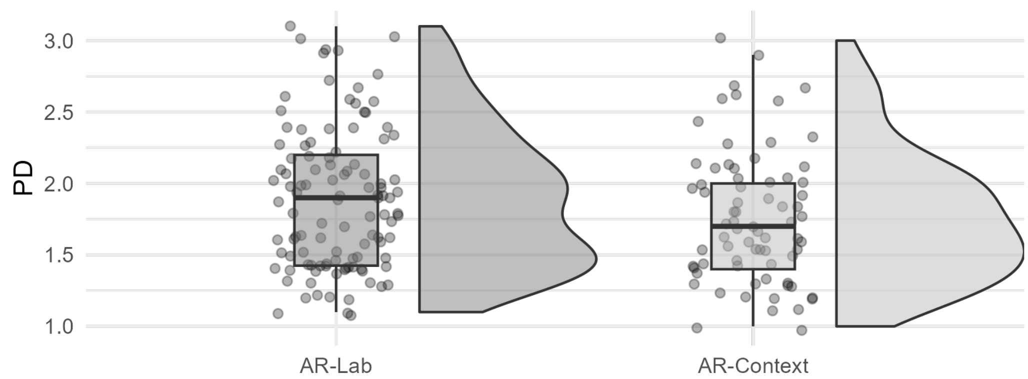

Figure C2: Donation levels in the AR-Lab and AR-Context