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ORIGINAL ARTICLE

Planting trees in the metaverse changes self-identity and improves pro-environmental interests and attitudes towards the physical world

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Abstract

As we spend more time in virtual reality (VR) and the metaverse, it becomes increasingly important to understand how our experiences in the metaverse impact self-perception and behaviours in the physical world. This research thus examines how performing pro-environmental behaviours in VR influences environmental self-identity and pro-environmental interests and attitudes towards the physical world. Two experiments were conducted where participants engaged in one of two distinct VR tasks: planting trees (tree condition) or placing neutral objects (control condition) in a virtual environment. Study 1 ($n=91$) showed that planting virtual trees significantly increased environmental self-identity compared to placing sheds in the control condition. Building on this, Study 2 ($n=97$) found that heightened environmental self-identity following virtual tree planting mediated the relationship between condition and subsequent pro-environmental interests and attitudes towards physical nature. These findings demonstrate the link between performing pro-environmental behaviours in VR and pro-environmental engagement in the physical world. They underscore the influence of virtual behaviours on self-identity, and the potential of VR as a tool for environmental sustainability efforts.

Keywords Virtual nature · Pro-environmental behaviour · Self-identity · Self-perception · Virtual reality · Metaverse

1 Introduction

In recent years, virtual reality (VR) has emerged as a transformative technology, offering users immersive and interactive virtual experiences (Hardiess et al. 2015; Zhang et al. 2022). While current VR applications are often limited to specific activities or environments, the metaverse expands these possibilities by offering users the opportunity to engage in a vast, interconnected virtual space where entire communities can form, evolve, and interact in ways that parallel physical societies. As these virtual environments become more sophisticated, they will continue to shape how we work, socialize, and engage with virtual spaces, with the potential to become seamlessly integrated into daily life (Damar 2021). However, a concern arises—how will virtual behaviours performed in the metaverse impact our actions in the physical world, our community around us, and even our sense of self?

Self-identity refers to prominent aspects of self-perception (Sparks and Shepherd 1992) and is the label one uses to describe oneself (Cook et al. 2002). Self-identity can be influenced by various aspects of one's life—from the behaviours one performs (Charng et al. 1988) to the possessions

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one owns (Wheeler and Bechler 2021). Given that virtual worlds can offer users immersive and interactive experiences (Knutzen and Kennedy 2012), it is plausible that VR can alter users' self-identity. Since an individual's self-identity is known to shape their attitudes and behaviours (Stets and Burke 2003; Stryker and Burke 2000), a transformation in self-identity due to VR could in turn lead to changes in attitudes and actions in the physical world.

To explore the link between virtual-world and physical-world behaviours, we focused on pro-environmental behaviours performed in VR. Kollmuss and Agyeman (2002) defined pro-environmental behaviour as actions that "consciously seek to minimize the negative impact of one's actions on the natural and built world" (p. 240). As engagement with virtual spaces increases, individuals are starting to buy land and real estate in the metaverse (Hutson et al. 2023). This suggests that the metaverse has its own digital environment that requires conservation, development, and maintenance, mirroring environmental concerns of the physical world. We thus expand the notion of the built world to include the digital realm and propose that virtual behaviours in the metaverse can be considered pro-environmental when they aim at improving or maintaining the virtual environment.

While past research has largely focused on the benefits of exposure to virtual nature on environmental outcomes (Chirico et al. 2023; Hofman et al. 2022; Deringer and Hanley 2021; Whitburn et al. 2018), we seek to investigate how active participation in pro-environmental behaviours in VR impacts self-perception, specifically one's sense of environmental self-identity. We further test if this shift in self-perception can lead to the promotion of pro-environmental interests and attitudes towards physical nature. In doing so, we aim to offer insights into the influence of virtual behaviours on psychological identity and its behavioural outcomes in the physical world.

1.1 Self-perception and environmental self-identity

According to *self-perception theory*, individuals construct the perception of themselves and their internal states by observing their own behaviour (Bem 1972). This process has been illustrated and supported by empirical studies across multiple domains. For example, using a pen from MIT influenced how intelligent or hardworking participants perceived themselves to be (Park and John 2010), while volunteering increased self-reported empathy and social responsibility (Brunelle 2001). In the context of environmental attitudes, participants who had been reminded of their past pro-environmental behaviours subsequently perceived themselves as having more supportive attitudes towards the natural environment, compared to participants who were reminded of past anti-environmental behaviours—a key finding from the foundational work of Chaiken and Baldwin (1981) that has greatly influenced the field. These findings collectively show how our experiences and behaviours shape perceptions of the self, which has implications for the formation of more stable attitudes and identities.

Self-identity represents a stable and enduring aspect of an individual's self-perception, encompassing one's beliefs, values, interests, and roles (Udall et al. 2021). Self-identity is often shaped by a combination of internal factors (such as personal values and beliefs) and external factors (such as culture, social roles, and life experiences). It represents a broader and more long-term understanding of one's self. Individuals who endorse an identity are more likely to engage in behaviours that align with the identity (Stets and Burke 2003; Stryker and Burke 2000). In particular, environmental self-identity refers to the extent to which one identifies oneself as a person who partakes in environmentally friendly actions (van der Werff et al. 2013). This concept extends beyond the mere adoption of pro-environmental behaviours, involving an integration of these behaviours into their self-concept, thus serving as a motivational force that drives individuals to act in ways that are congruent with their eco-conscious self-image.

Research indicates that when individuals engage in pro-environmental behaviours, their actions can strengthen their environmental self-identity (Chaiken and Baldwin 1981; Lacasse 2016; van der Werff et al. 2014a, b). Furthermore, individuals who identify themselves as being environmentally friendly are more likely to engage in pro-environmental behaviours, given that these behaviours validate their self-identity (Callero 1985). For example, identifying as a recycler significantly predicted both intentions to recycle and actual recycling behaviour, above and beyond other variables like attitudes, perceived behavioural control, and norms (Nigbur et al. 2010). Similarly, manipulating environmental self-identity increased participants' preferences for sustainable, though costlier products (van der Werff et al. 2013). These findings emphasize the close link between environmental self-identity and environmental engagement, underscoring its potential as a key factor in fostering a more sustainable future.

1.2 VR experiences and pro-environmental outcomes

Research in VR has demonstrated that virtual environments can closely mimic the physical world, and in turn influence users' beliefs, emotions, and behaviors (Sanchez-Vives and Slater 2005). For example, Reese et al. (2022) compared the effects on well-being between participants who visited a physical urban forest and those who experienced a

similar forest via immersive VR, and found similar well-being outcomes between the two groups. Similarly, Matilla et al. (2020) found that both physically visiting forests and experiencing them through VR produced equivalent restorative effects. These findings underscore the psychological equivalence of immersive VR experiences to physical-world interactions, and suggest that VR experiences can generate similar psychological outcomes as physical-life experiences.

While research exploring the impact of VR on self-identity is still sparse, preliminary studies indicate significant effects on other aspects of self-perception like self-efficacy. For example, physician assistant students experienced an increase in self-efficacy following a VR operating room simulation (Francis et al. 2020). Likewise, students engaged in a virtual simulation designed to teach laboratory safety procedures reported enhanced self-efficacy (Makransky et al. 2019). These examples highlight the potential of VR experiences in shaping self-perception, suggesting that its effects on self-identity is a promising area for further investigation.

Meanwhile, a number of studies have investigated the impact of VR experiences on pro-environmental behaviours. Still, the predominant focus has been on the mere exposure to nature in VR (e.g., 360-degree videos, nature exploration) and its influence on subsequent pro-environmental behaviours (Chirico et al. 2023; Hofman et al. 2022; Deringer and Hanley 2021; Whitburn et al. 2018). For instance, a study found that those who were exposed to awe-inspiring virtual nature took more flyers advocating against plastic production, compared to those who were in a control group exposed to an empty virtual room (Chirico et al. 2023). Another study by Hofman et al. (2022) found that groups who participated in a virtual marine tour exhibited similar conservation behaviors as those who experienced an actual marine tour. However, the metaverse goes beyond mere exposure to nature and offers avenues for active participation in diverse activities, such as planting trees, recycling trash, and growing crops in the virtual world.

The question then arises: How do these virtual pro-environmental behaviours influence our perceptions and actions towards the physical environment? A limited number of studies have attempted to answer this question. For example, Ahn et al. (2015) found that participants who planted a tree in VR were more willing to reduce paper consumption than those who cut down a tree. However, due to the lack of a baseline, it was unclear if the effect was due to the decrease of pro-environmental intentions caused by removing trees, or the increase of pro-environmental intentions caused by growing trees. In a separate study by Plechata et al. (2022), participants selected their meals in VR and witnessed the environmental impact of their choices. These participants in turn tended to opt for diets with a lower carbon footprint compared to those who were not exposed to the VR consequences. Regardless, it's important to note that the behaviours Plechata et al. (2022) examined in both the virtual and physical worlds were identical, specifically in terms of food selection. This similarity raises questions about the broader applicability of these findings to different contexts. In contrast, our study aims to explore whether VR experiences can alter one's self-identity and subsequently influence behavioural interests and attitudes in the physical world that differ from those experienced in VR, assessing the generalizability of VR interventions.

2 Present research

Two studies were conducted to investigate the influence of virtual pro-environmental behaviours on environmental self-identity, and the consequent increase in pro-environmental interests and attitudes towards the physical world. In Study 1, participants either planted trees (tree condition) or placed wooden sheds (control condition) in a virtual plot of land, before being measured on environmental self-identity. We hypothesized that *participants in the tree condition would exhibit a higher sense of environmental self-identity compared to those in the control condition* (Hypothesis 1).

In Study 2, we expand on Study 1 to examine the downstream effects of environmental self-identity on pro-environmental outcomes. Participants were assigned to either plant trees (tree condition) or place streetlamps (control condition) in a virtual neighbourhood. After which, participants' environmental self-identity, pro-environmental interests, and pro-environmental attitudes were assessed. We hypothesized that *participants in the tree condition would report a stronger environmental self-identity than those in the control condition, and that this heightened environmental self-identity would mediate the relationship between virtual pro-environmental behaviours and subsequent pro-environmental interests and attitudes* (Hypothesis 2).

3 Study 1

3.1 Methodology

3.1.1 Participants

A total of 100 participants were recruited, all of whom were undergraduates who participated in exchange for course credits. However, nine participants faced technical disruptions with the VR headset, and therefore their responses were removed from subsequent analyses. The final sample

consisted of 91 participants (68 females, age M = 20.62, *SD* = 1.66). Participants comprised of Chinese (*n* = 67), Indians (*n* = 7), Malays (*n* = 6), and others (Caucasians and Filipinos; *n* = 11).

3.1.2 Procedure

Experiments were conducted individually and participants were randomly assigned to either the tree condition (*n* = 45), or control condition (*n* = 46). At the start of each session, participants were directed to a desk with a computer and informed that they would be engaging in a 5-min VR experience where they would either plant trees (tree condition) or place sheds (control condition) on a virtual plot of land. A 5-min duration was chosen based on pilot testing and prior research indicating that 5 min is sufficient to elicit psychological and physiological effects in VR, while minimizing the risk of fatigue or discomfort (e.g., Chan et al. 2023a, b; Mattila et al. 2020; Brown et al. 2013).

Additionally, sheds were selected for the control condition due to the sheds' neutrality and appropriateness within Study 1's virtual setting.

Before going through the VR experience, participants were told that the number of trees (or *sheds*) they would be given in VR would be determined by their performance on a number identification task. For the number identification task, participants were provided with a piece of paper containing a series of numbers. They were instructed to identify and circle all numbers with an even first digit and odd second digit (see Appendix A). The task consisted of a total of 320 numbers, divided into 4 sections of 80 numbers each.

This task was used to induce a sense of sacrifice for participants, because pro-environmental behaviours often require a sacrifice of time and effort, such as in volunteering or recycling (Steg et al. 2014). Participants were told that they had control over how much effort or time they wanted to invest into this task, and completing more sections would result in a higher number of trees (or *sheds*) they would receive later on. However, all participants received the same reward of 15 trees (or 15 *sheds*) regardless of performance.

After completing the number identification task, participants submitted their responses to the researcher, and are informed that they will receive their reward of 15 trees to plant (or *15 sheds to place*) in the virtual world. They are then directed to a swivel seat to commence the VR experience, administered via an Oculus Quest 2 headset. The VR environment used in this study was derived from a game titled "*Morels Homestead*", which is available on the Oculus Quest game store. Participants all started off on the same empty plot of land, with the only difference being the items they could access from the in-game inventory. For participants in the tree condition, their inventory contained 15 trees. For participants in the control condition, their inventory contained 15 sheds. Besides these 15 trees or sheds, there were no other items in the inventory.

Fig. 1 Trees on the plot of land

Fig. 2 Sheds on the plot of land

The researcher assisted participants in wearing the headset and, consistent with the default configuration of the VR game, provided them with a controller for their right hand. Instructions were provided on how to use the controller and participants were given time to practice with the controls before starting on the VR task. To plant a tree (or *place a shed*), they selected the object from their inventory, dragged it out, and placed it on the land. Once the 5-min limit had elapsed and participants planted all 15 trees (or *placed all 15 sheds*), the researcher ended the VR experience (Figs. 1 and 2).

Participants then returned to the computer to complete a survey. Once the survey was completed, participants were debriefed. The study protocol was approved by the University Ethics Committee (IRB-2022-314), and informed consent was obtained from all participants.

3.1.3 *Measures*

Environmental self-identity was measured with a scale adapted from Khan and Dhar's (2006) moral-self scale, as well as items from past studies on environmental self-identity (Lacasse 2016; van der Werff et al. 2013, 2014a). The 4-item scale includes items like "*I am green*" and "*I am eco-friendly*" (α = 0.94). Participants were asked to indicate their agreement to these statements with a 7-point Likert scale, where 1 = strongly disagree, and 7 = strongly agree.

Participants were also asked if they had any prior VR experience with a head-mounted display before the study (1 = yes, 0 = no), and whether they felt any symptoms of motion sickness (e.g., nausea, headache) on a scale from 1 = not much or not at all, to 5 = very much so. Overall, about half of the participants (57.1%) had never tried VR with a head-mounted device prior to the experiment, and ratings of cybersickness were generally low ($M = 2.26$, $SD = 1.34$). Finally, participants were asked for their age, gender and ethnicity at the end of the survey. The full list of items can be found in Appendix B.

3.2 Results and discussion

3.2.1 Environmental self-identity

We first conducted Levene's test and results did not provide sufficient evidence to reject the hypothesis of equal variances between groups ($p > 0.05$). Normality was evaluated using Shapiro–Wilk tests and Q–Q plots. In the tree condition, the Shapiro–Wilk test ($W = 0.916$, $df = 45$, $p = 0.003$) and Q–Q plot suggested deviations from normality, particularly in the tails. Similarly, in the control condition, the test ($W = 0.950$, $df = 46$, $p = 0.046$) and Q–Q plot confirmed significant non-normality. Due to the deviations from normality, we employed the Mann–Whitney U test to compare differences between conditions on environmental self-identity. However, in adherence to the Central Limit Theorem, which posits that the sampling distribution of the mean tends to be normal with a sufficiently large sample size ($n > 30$) (Freedman et al. 2007), we also conducted an independent samples t-test as a robustness check.

Results of the Mann–Whitney U test indicated a statistically significant difference between conditions ($U = 786.000$, $Z = -1.987$, $p = 0.047$). Those in the tree condition ($Mdn = 51.53$) showed higher environmental self-identity scores than those in the control condition ($Mdn = 40.59$). Consistent with this finding, the independent samples t-test indicated a significant effect of the condition on environmental self-identity, $t(89) = -2.04$, $p = 0.045$, Cohen's $d = 0.42$. Participants in the tree condition exhibited higher mean scores ($M = 4.52$, $SD = 1.12$) than those in the control condition ($M = 4.01$, $SD = 1.29$).

3.2.2 Gender, cybersickness and prior experience with VR

To account for potential confounding variables, an analysis of covariance was conducted with environmental self-identity as the dependent variable, and gender, cybersickness, and prior VR experience as covariates (Felnhofer et al. 2012; Mareta et al. 2022; Sagnier et al. 2020). Results indicate that, controlling for gender, cybersickness, and prior VR experiences, the effect of condition on environmental self-identity remained significant, $F(1,86) = 3.824$, $p = 0.054$. Gender ($F(1, 86) = 1.498$, $p = 0.224$), cybersickness ($F(1, 86) = 2.411$, $p = 0.124$), and prior VR experience ($F(1, 86) = 0.328$, $p = 0.568$) did not significantly predict environmental self-identity.

Study 1 demonstrated that engaging in pro-environmental behaviours in VR strengthened one's environmental self-identity, providing support for Hypothesis 1. In this case, participants who engaged in a virtual pro-environmental behaviour (planting trees) perceived themselves as more environmental relative to those who had engaged in a neutral behaviour (placing sheds).

4 Study 2

Building upon the findings of Study 1, Study 2 aimed to examine the outcomes of environmental self-identity fostered through virtual pro-environmental behaviours. Study 2 will also utilize a different VR environment than that used in Study 1 to examine the generalizability of previous findings in a different setting.

4.1 Methodology

4.1.1 Participants

A total of 107 participants were recruited for the second study. The sample used in this study was distinct from the one used in Study 1. Participants received course credits (n = 63) or SGD8 (n = 44) for their participation. Following the initial recruitment, 10 participants faced technical disruptions with the VR headset, and their responses were removed from subsequent analyses. Out of the remaining 97 participants, 61 were female and 36 were male, with a mean

age of 22.25 (SD = 3.50). Participants comprised of Chinese (n = 74), Indians (n = 9), Malays (n = 4), and others (Korean, Japanese, Burmese etc., n = 10).

4.1.2 Procedure

The procedure for the second study was similar to the first study. Participants would first complete the number identification task, before starting on the 5-min VR experience. They would then end the study with a survey. The key difference between Study 1 and Study 2 was the virtual environment used in the VR experience. Instead of an empty plot of land, Study 2's virtual environment was set in a suburban neighbourhood with houses and play equipment.

Participants were randomly assigned to the tree condition (n = 50), or control condition (n = 47) at the start of each session, and all participants started off in the same virtual neighbourhood. In the control condition, streetlamps were selected to be placed for their neutrality and suitability for the setting. Furthermore, their dimensions were approximately equivalent to those of the trees used in the tree condition.

Participants in the tree condition received 15 trees in their inventory, while participants in the control condition received 15 streetlamps in theirs. Similar to Study 1, no other items besides the trees (*streetlamps*) were in the inventory, and participants were given 5 min to finish placing these items in the neighbourhood (see Figs. 3 and 4).

4.1.3 Measures

Pro-environmental interest was assessed with the first measure, where participants were introduced to a local environmental sustainability club called "Eco Warriors", a club that aims to promote an environmentally conscious Singapore. They were then asked to indicate if they would be interested to sign up for the club's newsletter (1 = yes, 0 = no), as a measure of interest in environmental news. Eco Warriors was a fictional organization made up for this study, but participants were unaware of this until the end of the study.

Secondly, we used the Willingness to Sacrifice for the Environment (WSE) scale adapted from Davis et al. (2011) as a measure of pro-environmental attitudes. The 5-item scale includes items like "*I am willing to give things up that I like doing if they do not improve the natural environment*" and "*I am willing to go out of my way to do what is best for the natural environment*" (α = 0.862). All items were measured on a 9-point Likert scale, with 1 = do not agree at all, and 9 = agree completely.

Environmental self-identity was measured with the same 4-item scale used in Study 1 (α = 0.926). Similarly, participants were also asked if they had any prior VR experience

Fig. 3 Trees in the neighbourhood

Fig. 4 Streetlamps in the neighbourhood

and if they felt any symptoms of motion sickness during the study. Overall, about half of the participants (47.4%) had never tried VR with a head-mounted device prior to the experiment, and ratings of cybersickness were generally low (M = 2.67, SD = 1.30). Finally, participants were asked for their age, gender and ethnicity at the end of the survey. All items used can be found in Appendix B.

4.2 Results and discussion

Chi-square tests of independence, independent samples t-tests and Mann–Whitney U tests were performed to examine the main effect of planting trees in VR on pro-environmental interests and attitudes. In addition, mediation analyses were conducted to determine the role of

environmental self-identity as a mediator in the aforementioned relationships.

4.2.1 Interest in environmental news

A chi-square test of independence was used to examine the relationship between condition and interest in signing up for the environmental newsletter, given that both variables are categorical. Assumption checks confirmed that all expected frequencies exceeded 5. Results showed no significant relationship between condition and interest to sign up for the environmental newsletter, χ^2 (1) = 1.95, $p = 0.162$. In other words, planting virtual trees did not directly influence interest in environmental news more than placing street lamps. The percentages of yes and no responses between both groups are denoted in the table below (Table 1).

4.2.2 Willingness to sacrifice for environment

Levene's test did not indicate significant differences in variances between groups ($p > 0.05$). Shapiro–Wilk tests and Q–Q plots indicated normality for both groups. In the tree condition, the Shapiro–Wilk test demonstrated normality, $W = 0.977$, $df = 50$, $p = 0.449$; while the Q–Q plot further supported this. Similarly, in the control condition, the Shapiro–Wilk test confirmed normality, $W = 0.973$, $df = 47$, $p = 0.449$, with the Q–Q plot showing consistent results. As such, an independent samples t-test was conducted to examine the difference in willingness to sacrifice for the environment between conditions. Results showed no significant main effect of planting virtual trees on willingness to sacrifice for the environment. Participants in the tree condition showed similar WSE scores ($M = 6.04$, $SD = 1.30$) as those in the control condition ($M = 5.78$, $SD = 1.37$), with $t(95) = -.00$, $p = 0.337$.

4.2.3 Environmental self-identity

Levene's test did not provide sufficient evidence to reject the hypothesis of equal variances between groups ($p > 0.05$). In the control condition, the Shapiro–Wilk test supported the assumption of normality, $W = 0.963$, $df = 47$, $p = 0.146$. The Q–Q plot further corroborated this, showing data points that closely follow the expected normal line. However, in the tree condition, the Shapiro–Wilk test ($W = 0.863$, $df = 50$, $p = 0.000$) revealed significant deviations from normality, with the Q–Q plot also showing notable deviations from expected normal distribution. Given these mixed normality results, the Mann–Whitney U test was employed to compare environmental self-identity between conditions, and as with Study 1, an independent samples t-test was also conducted as a robustness check due to moderate sample sizes ($n > 30$).

The Mann–Whitney U test results indicated a significant difference between conditions ($U = 839.500$, $Z = -2.435$, $p = 0.015$). Those in the tree condition ($Mdn = 55.72$) showed higher environmental self-identity scores than those in the control condition ($Mdn = 41.86$). Similarly, results of the independent samples t-tests revealed that those in the tree condition ($M = 4.80$, $SD = 1.16$) showed higher environmental self-identity scores than those in the control condition ($M = 4.24$, $SD = 1.26$), with $t(95) = -2.26$, $p = 0.026$, Cohen's $d = 0.462$. In other words, planting trees in VR influenced participants' sense of environmental self-identity.

While there was no direct effect of planting virtual trees on both measures of pro-environmental interests and attitudes, an indirect effect may still exist through a mediator (James et al. 2006; Shrout and Bolger 2002). Given that self-identity plays a key role in influencing behaviours and attitudes (van der Werff et al. 2013; Nigbur et al. 2010), we tested whether environmental self-identity served as a mediator. Mediation analyses were conducted to determine if there was an indirect effect through environmental self-identity, with significance of a mediation effect determined by confidence intervals that do not contain zero (Hayes and Scharkow 2013).

4.2.4 Interest in environmental news and environmental self-identity

To test Hypothesis 2, mediation analysis was conducted using Model 4 of the PROCESS macro (version 4.1; Hayes and Scharkow 2013) through SPSS. The model predicting environmental self-identity from condition was significant, $F(1, 95) = 5.13$, $p = 0.023$, explaining 5.12% of the variance ($R2 = 0.0512$). Condition significantly predicted environmental self-identity ($b = 0.556$, $SE = 0.245$, $t(95) = 2.26$, $p = 0.026$).

Additionally, the logistic regression model for interest in environmental news was significant, $\chi2(2) = 8.53$, $p = 0.014$, with McFadden's $R2 = 0.0743$. Condition did

Table 1 Interest in environmental news across conditions

		Condition				Total	
		Tree		Control			
		n	%	n	%	n	%
Interest in environmental news	Yes	17	34.0	10	21.3	27	27.8
	No	33	66.0	37	78.7	70	72.2
Total		50	100.0	47	100.0	97	100.0

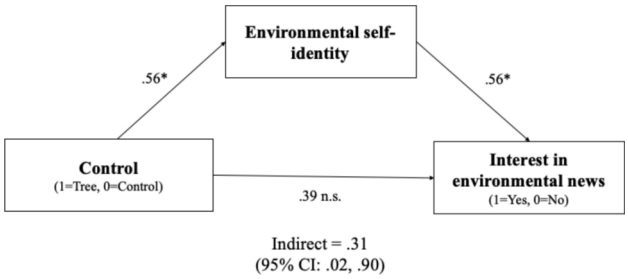

Fig. 5 Mediation analysis testing whether the effect of condition on interest in environmental news is mediated by environmental self-identity. Unstandardized path coefficients are shown. *$p<0.05$

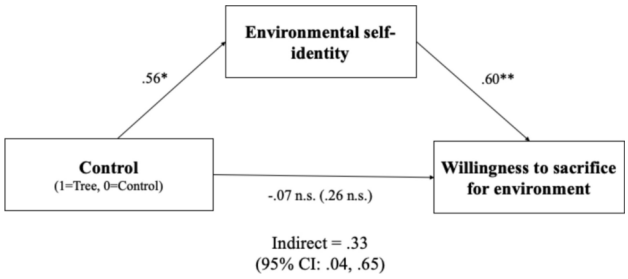

Fig. 6 Mediation analysis testing whether the effect of condition on interest in willingness to sacrifice for environment is mediated by environmental self-identity. Unstandardized path coefficients are shown. The direct effect reported in parentheses represents the association between condition and willingness to sacrifice for environment when environmental self-identity is excluded. *$p<0.05$, **$p<0.01$

not significantly predict interest in environmental news ($b=0.392$, $SE=0.488$, $Z=0.803$, $p=0.422$). However, environmental self-identity significantly predicted interest in the environmental newsletter ($b=0.564$, $SE=0.242$, $Z=2.33$, $p=0.020$). The direct effect of condition on interest in environmental news was not significant ($b=0.392$, $SE=0.488$, $Z=0.803$, $p=0.422$), but the indirect effect was significant ($b=0.314$, $SE=0.231$, 95% CI [0.018, 0.898]). This demonstrates that environmental self-identity mediated the relationship between planting trees in VR and interest in environmental news (Fig. 5).

4.2.5 Willingness to sacrifice for environment and environmental self-identity

Similarly, mediation analysis was conducted using Model 4 of the PROCESS macro (version 4.1; Hayes and Scharkow 2013) through SPSS. The model predicting environmental self-identity from condition was significant, $F(1, 95)=5.13$, $p=0.023$, explaining 5.12% of the variance ($R^2=0.0512$). Condition significantly predicted environmental self-identity ($b=0.556$, $SE=0.245$, $t(95)=2.26$, $p=0.026$).

The regression model predicting willingness to sacrifice for the environment from environmental self-identity and condition was also significant, $F(2, 94)=20.55$, $p<0.0001$, with 30.42% of the variance explained ($R^2=0.3042$). Condition did not significantly directly predict WSE scores ($b=-0.073$, $SE=0.234$, $t(94)=-0.312$, $p=0.756$), but environmental self-identity did ($b=0.601$, $SE=0.095$, $t(94)=6.31$, $p<0.0001$).

The total effect of condition on WSE scores was not significant ($b=0.261$, $SE=0.270$, $t(95)=0.965$, $p=0.337$), and similarly, the direct effect of condition on WSE remained non-significant ($b=-0.073$, $SE=0.234$, $t(94)=-0.312$, $p=0.756$). However, the indirect effect of condition on WSE through environmental self-identity was significant ($b=0.334$, $SE=0.153$, 95% CI [0.043, 0.649]). These findings thus demonstrate that environmental self-identity mediated the effect of planting virtual trees on willingness to sacrifice for the environment (Fig. 6).

4.2.6 Gender, cybersickness and prior experience with VR

Similar to Study 1, an analysis of covariance was conducted to account for potential confounding variables. Environmental self-identity was examined as the dependent variable, and gender, cybersickness, and prior VR experience as covariates. Results indicate that, controlling for gender, cybersickness, and prior VR experiences, the effect of condition on environmental self-identity remained significant, $F(1,92)=5.661$, $p=0.019$. Gender ($F(1, 92)=0.642$, $p=0.425$), cybersickness ($F(1, 92)=0.273$, $p=0.603$), and prior VR experience ($F(1, 92)=0.414$, $p=0.522$) did not significantly predict environmental self-identity.

Altogether, Study 2 successfully replicated findings of Study 1, providing further evidence that performing pro-environmental behaviours in VR strengthens environmental self-identity, even after accounting for variables like cybersickness and gender. Additionally, we also found that this heightened sense of environmental self-identity served as a mediator for the relationship between VR pro-environmental behaviours and subsequent pro-environmental interests and attitudes, thus supporting Hypothesis 2.

5 General discussion

In understanding the relationship between our increasing involvement with virtual worlds and the environment, our study highlights the impact of VR on how individuals perceive and construct their sense of self in the context of the natural world. As we spend an increasing amount of time in the metaverse, the concern about its potential influence on our connection with the physical world, community, and self becomes more pronounced. Across two studies, our findings point to a positive association between virtual pro-environmental behaviours and environmental self-identity. Moreover, this heightened environmental self-identity was

subsequently linked to increased pro-environmental interests and attitudes towards the physical world. In this discussion, we thus delve into the relationship between virtual pro-environmental behaviours, environmental self-identity, and pro-environmental outcomes.

Study 1 investigated the effects of virtual pro-environmental behaviours on environmental self-identity. Findings support H1—participants who planted trees in the virtual environment reported stronger environmental self-identity compared to those who placed wooden sheds. This suggests that engaging in pro-environmental behaviours, even in a virtual environment, can foster environmental self-identity. Building upon Study 1's results, Study 2 examined the downstream impacts of environmental self-identity on pro-environmental outcomes. Consistent with H2, we observed the positive influence of planting virtual trees on both pro-environmental interests and attitudes mediated through environmental self-identity. This suggests that environmental self-identity built through virtual experiences may have positive implications for physical-world pro-environmental outcomes.

Findings from these studies contribute to existing literature in environmental psychology in several ways. First, our results supports prior research on the importance of environmental self-identity in promoting pro-environmental behaviour (e.g., Brick and Lai 2018; Carfora et al. 2017; Khare 2015), beyond other predictors of pro-environmental behaviours such as nature connectedness (e.g. Chan et al. 2023a, b; Martin et al. 2020; Rosa et al. 2018). Focusing on environmental self-identity offers a deeper understanding of individuals' dispositions towards the environment, in turn, facilitating broader predictions of diverse pro-environmental behaviours than more context-specific constructs like nature connectedness (van der Werff et al. 2013). Notably, our studies suggest that engaging in virtual pro-environmental behaviours—such as planting virtual trees—can potentially influence one's identity as an environmentally friendly person, even in the absence of direct, tangible benefits to the physical natural world. This underscores the unique potential of virtual experiences in shaping self-perceptions and contributing to a more enduring commitment to environmental sustainability across broader contexts. Furthermore, our studies extend previous studies that have shown the positive impact of nature exposure on pro-environmental behaviours (e.g., Hofman et al. 2022; Whitburn et al. 2018) with an experimental design that allows attribution of observed effects specifically to the engagement in virtual pro-environmental behaviours, beyond the influence of mere nature exposure.

While our study revealed an indirect effect of virtual pro-environmental behaviours on subsequent pro-environmental interests and attitudes through environmental self-identity, a direct main effect was not observed. This may suggest that virtual behaviours alone may not be enough to shift pro-environmental attitudes and interests without a meaningful self-referential process. While planting virtual trees may not have triggered a conscious attitude change, it may have subtly reinforced environmental self-identity, which in turn influenced pro-environmental interests and attitudes. Another plausible explanation is that the neutral behaviour introduced in Study 2 (i.e. placing of streetlamps) might have primed concepts associated with pro-sociality, which has been closely linked to pro-environmental behaviour (Tamar et al. 2021; Gärling et al. 2003). Similarly, nature exposure has been associated with pro-sociality (Arbuthnott 2023; Liu et al. 2023) and positive affect (Bratman et al. 2021; Meidenbauer et al. 2020), both of which also predict pro-environmental behaviour (Chatelain et al. 2018; Gärling et al. 2003). These findings highlight the nuanced interplay between virtual experiences, environmental cues, and the multifaceted drivers of pro-environmental behaviours, suggesting a need for further exploration.

Beyond contributions to environmental psychology, our research also provides support for Bem's (1972) self-perception theory and corroborates findings from past scholars (e.g., Lacasse 2016; van der Werff et al. 2014b). Specifically, we find that individuals form a sense of their environmental self through observations of their own pro-environmental behaviour. Our findings further extends this understanding to the context of VR, illustrating that behaviours performed even in the virtual space may also shape individuals' self-perceptions, though further research is required to understand the extent of this influence. In contrast to existing avatar-centric VR research that have looked into the Proteus effect, where changes in avatar appearance influences users' behaviours and attitudes (e.g., Navarro et al. 2022; Ratan et al. 2020; Yee and Bailenson 2007), or embodiment studies that look into how embodying different avatars can affect users' self-perception (e.g., Spangenberger et al. 2022; Ahn et al. 2014, 2016), our investigation instead delves into the impact of users' own actions within the virtual environment. Our study thus offers a broader understanding of how specific virtual experiences, beyond avatars, can shape individuals' perceptions and behaviours.

In exploring future avenues in the metaverse, presence, the feeling of "*being there*" in a virtual environment, has been shown to enhance psychological effects in virtual experiences (Yeo et al. 2020; Persky and Blascovich 2008). As technology continues to evolve, we may expect to see that the greater presence evoked by virtual experiences might intensify the impact on users' environmental self-identity. Future research should thus explore the relationship between presence and the psychological and behavioural outcomes of virtual pro-environmental behaviour. Another crucial

aspect within the metaverse is the inclusion of other avatars, introducing a social dimension to virtual experiences. Social presence theory, examining the sense of being with others in mediated environment, has illustrated the influence of others' presence on shaping attitudes and behaviours (Oh et al. 2018; Hassanein and Head 2007; Fogg and Tseng 1999). As such, a potential avenue for exploration is whether the observation of others engaging in virtual pro-environmental behaviours similarly affects users' environmental self-identity and subsequent pro-environmental outcomes.

Past research has shown that prior experiences with VR and cybersickness may affect user experiences in VR (Mareta et al. 2022; Sagnier et al. 2020; Litleskare and Calogiuri 2019). Therefore, we conducted additional analyses (see Appendix C) to examine if prior VR experience and cybersickness moderates the relationship between planting of virtual trees and environmental self-identity. While we found no moderating effects of prior VR experience, we found a marginally negative direct effect of cybersickness on environmental self-identity in Study 1. In Study 2, both the direct effects of cybersickness and its interaction with planting virtual trees were significant predictors of environmental self-identity. These results suggests that cybersickness may subtly undermine the overall positive effects by impairing users' environmental perceptions. This underscores the importance of designing VR experiences that minimize cybersickness to enhance the efficacy of future environmental interventions.

Simultaneously, as virtual nature becomes increasingly integrated into our lives, questions arise about its potential to replace physical-world nature experiences (Kahn et al. 2009). While our current findings show that VR experiences can improve interests and attitudes towards the physical world, there is a possibility that people may choose to invest in the virtual environment more than the physical environment as virtual activities become increasingly integrated into our lives. This may lead to detrimental effects on the physical environment. Hence, examining whether individuals will be more inclined to invest time and effort into virtual pro-environmental behaviours over actions in the physical world requires further investigation. Future studies can thus delve into the psychological antecedents and consequences of this shift toward preferences for virtual environmental engagement over physical world actions.

5.1 Practical implications

Our findings contribute to the emerging discussion on the role of VR and the metaverse in environmental conservation efforts. As VR technologies gain popularity, understanding its potential influence on how people engage with and care for the natural environment becomes increasingly important. While our results are promising, they should be viewed as an initial step rather than a definitive conclusion of the effects of virtual pro-environmental behaviours. We suggest that the metaverse and VR could potentially serve as a promising tool for promoting pro-environmental behaviours, once more research has been done to establish its efficacy. By creating immersive environments where users can participate in activities such as planting trees, farming crops, or recycling materials, organizations, institutions, and policymakers might foster a stronger environmental self-identity among users. This in turn could positively influence intentions to engage in similar behaviours in the physical world.

5.2 Limitations

Limitations of our research should also be acknowledged. Firstly, the manipulation of pro-environmental behaviour in both studies only used one type of pro-environmental behaviour (i.e., planting trees) in a virtual nature environment. To ensure generalizability of these findings, future studies could examine a broader range of behaviours (e.g., cleaning up litter, sorting out recyclables) in other virtual environments (e.g., urban city). Furthermore, the notable gender disparity, with a higher proportion of females than males, in both samples limits the generalizability of our findings. Subsequent research should therefore strive for more balanced representation across gender groups.

Another limitation arises from the differing virtual environments used in Study 1 and Study 2 which could have influenced participants' interpretations of the environmental tasks. For instance, placing a wooden shed in Study 1's natural setting may have been perceived as anti-environmental rather neutral, contrary to our intentions. Participants might also not consider planting trees in VR as pro-environmental. To address this, future research should include a manipulation check to verify that the virtual tasks are perceived as intended by participants. This manipulation check will also specifically ensure that the act of planting trees in the VR environment, our experimental condition, is consistently viewed as pro-environmental across different settings, thereby confirming the intended pro-environmental framing of this activity.

Additionally, we did not include a pre-test measurement of participants' pro-environmental tendencies. Future investigations could benefit from incorporating such measures to better understand how individual predispositions may interact with virtual pro-environmental behaviours to influence environmental outcomes. Moreover, our survey items could possibly result in participant bias, where participants may infer the study's purpose and provide responses they perceive as expected. To mitigate this bias, future studies could consider including filler items between surveys.

Furthermore, our study did not randomize the order of survey items, which may have introduced order effects. Subsequent research should address this by randomizing item sequences to enhance the robustness of the findings.

Lastly, our studies only examined immediate effects of virtual behaviours in a lab setting. As such, long-term effects of VR on actual pro-environmental behaviours in physical-world settings should also be investigated in the future to ascertain the generalizability and sustainability of these effects.

6 Conclusion

This research contributes to our understanding of VR and the metaverse in shaping our self-perceptions and attitudes towards the natural environment. By examining the effects of virtual pro-environmental behaviours, our results suggest that virtual worlds may play a role in fostering environmental self-identity, with potential implications for promoting engagement in pro-environmental behaviours in the physical world. These results not only align with past research in environmental psychology, but expand our knowledge on the factors influencing pro-environmental behaviours within the unique context of VR. At the same time, our results highlight key nuances. The absence of a direct effect between virtual behaviours and pro-environmental outcomes suggest that self-identity may be a necessary mechanism for attitude change. Furthermore, the impact of cybersickness observed in our study demonstrate the importance of user-friendly VR designs to ensure its effectiveness. Given the exploratory nature of this study, further research is needed to examine a broader range of virtual behaviours, investigate long-term effects, and explore the role of social dynamics in VR settings. As technology continues to advance and virtual worlds gain increasing popularity, addressing these questions will be key to understanding how VR can be effectively incorporated into educational and intervention programmes to promote a more sustainable future.

Appendix A: Number identification task

Your task is to circle all the numbers with an even first digit and an odd second digit. For example, you should circle "25", because the first digit (2) is even and the second digit is odd (5).

Section 1									
48	21	68	13	19	63	24	27	22	18
88	37	73	39	66	43	27	93	91	59
26	52	53	37	48	44	86	18	74	44
65	22	63	78	43	71	64	15	82	83
58	98	96	23	69	42	74	63	92	31
58	73	28	27	68	46	82	66	68	81
32	95	47	62	35	46	76	79	59	91
83	85	71	82	53	12	35	47	49	31
Section 2									
19	26	47	71	91	46	56	53	39	13
62	84	46	13	38	28	45	34	41	68
43	25	54	75	61	63	56	31	18	63
21	61	97	46	98	54	17	96	74	38
31	87	29	81	26	32	14	16	52	64
69	39	66	96	21	73	33	97	51	98
73	52	37	62	22	58	46	23	12	46
96	62	92	64	43	78	93	16	84	69
Section 3									
58	18	26	32	88	61	82	44	53	96
64	68	38	29	81	41	62	42	92	15
97	45	17	79	73	19	21	86	88	49
78	66	29	22	74	79	68	81	37	58
27	48	14	82	79	91	18	43	92	24
75	67	81	54	24	64	32	14	75	69
28	71	83	68	54	85	61	31	74	64
32	22	46	87	79	38	87	73	19	21
Section 4									
38	67	58	72	56	82	34	62	66	59
19	75	24	92	57	44	81	73	91	75
27	44	65	38	53	67	85	66	71	18
38	15	72	38	85	98	32	73	88	34
46	31	89	17	52	46	31	42	89	29
61	57	18	52	85	79	48	67	51	16
47	91	44	57	63	85	19	58	41	75
86	71	87	43	32	25	29	82	46	72

Appendix B: Measures used

Study 1 measures (in order of presentation)

1. **Environmental self-identity**
    1. I am pro-environmental
    2. I am environmentally conscious
    3. I am green
    4. I am eco-friendly

- 7-point Likert scale (1 = Strongly disagree, 7 = Strongly agree)

2. **Prior VR experience and cybersickness check**

- Have your tried VR with a head-mounted display before? (Excluding today's VR experience)
  - Yes
  - No
- Think back to the VR experience you just had. To what extent did you feel symptoms of motion sickness (e.g., nausea, headache, dizziness)?
  - 5-point Likert scale (1 = not much or not at all, 5 = very much)

Study 2 measures (in order of presentation)

1. **Interest in environmental group**

1. Eco Warriors is a new local environmental sustainability club which aims to promote an environmentally conscious Singapore.
   Please indicate if you would like to sign up for the newsletter below. If so, you will be provided a separate link for the newsletter after the study.

- Yes, I am interested to sign up for the newsletter.
- No, I am not interested to sign up for the newsletter.

2. **Willingness to sacrifice for the environment**

1. I am willing to give things up that I like doing if they do not improve the natural environment.
2. I am willing to take on responsibilities that will help benefit the natural environment.
3. I am willing to do things the benefit the natural environment, even if I'm not thanked for my efforts.
4. Even when it is inconvenient to me, I am willing to do what I think is best for the natural environment.
5. I am willing to go out of my way to do what is best for the natural environment.

- 9-point Likert scale (1 = Do not agree at all, 9 = Agree completely)

3. **Environmental self-identity**

1. I am pro-environmental
2. I am environmentally conscious
3. I am green
4. I am eco-friendly

- 7-point Likert scale (1 = Strongly disagree, 7 = Strongly agree)

4. **Prior VR experience and cybersickness check**

- Have your tried VR with a head-mounted display before? (Excluding today's VR experience)
  - Yes
  - No
- Think back to the VR experience you just had. To what extent did you feel symptoms of motion sickness (e.g., nausea, headache, dizziness)?
  - 5-point Likert scale (1 = not much or not at all, 5 = very much)

Appendix C: Supplementary moderation analyses

This appendix details supplementary moderation analyses conducted to explore the potential influence of prior VR experience and cybersickness on the relationship between condition and environmental self-identity in Study 1 and 2.

The following moderation analyses were conducted using Model 1 of the PROCESS macro (version 4.1; Hayes and Scharkow 2013) through SPSS, incorporating prior VR experience as a moderator, with gender and cybersickness as covariates.

For Study 1, the analysis included data from 91 participants. The overall model accounted for 11.53% of the variance in environmental self-identity ($R2 = 0.3396$, $F(5, 85) = 2.2165$, $p = 0.0600$).

Prior VR experience ($b = 0.1173$, $SE = 0.3565$, $t(88) = 0.3291$, $p = 0.7429$), gender ($b = 0.3913$, $SE = 0.2923$, $t(88) = 1.339$, $p = 0.2945$) and cybersickness ($b = -0.1406$, $SE = 0.0999$, $t(88) = -1.407$, $p = 0.1629$) did not significantly predict environmental self-identity. On the other hand, a significant positive effect of condition on environmental self-identity was found ($b = 0.7618$, $SE = 0.3515$, $t(88) = 2.168$, $p = 0.0330$). The interaction between condition and prior VR experience was not significant ($b = -0.5419$, $SE = 0.5137$, $t(88) = -1.055$, $p = 0.2945$).

For Study 2, the analysis included data from 97 participants. The overall model accounted for 6.83% of the

variance in environmental self-identity (R2 = 0.2613, F(5, 91) = 1.333, p = 0.2573).

Prior VR experience (b = 0.2889, SE = 0.3743, t(94) = 0.7719, p = 0.4422), gender (b = −0.2082, SE = 0.2648, t(94) = −0.7862, p = 0.4338) and cybersickness (b = −0.0561, SE = 0.0999, t(94) = −0.5612, p = 0.5860) did not significantly predict environmental self-identity. However, a marginally significant positive effect of condition on environmental self-identity was found (b = 0.7286, SE = 0.3752, t(94) = 1.942, p = 0.0553). The interaction between condition and prior VR experience was not significant (b = −0.2332, SE = 0.5134, t(94) = −0.4543, p = 0.6507).

The following moderation analyses were conducted using Model 1 of the PROCESS macro (version 4.1; Hayes and Scharkow 2013) through SPSS, incorporating cybersickness as a moderator, with gender and prior VR experience as covariates.

For Study 1, the analysis included data from 91 participants. The overall model accounted for 11.72% of the variance in environmental self-identity (R2 = 0.1172, F(5, 85) = 2.2562, p = 0.0560).

Condition (b = 0.0097, SE = 0.5196, t(88) = 0.0186, p = 0.9852), gender (b = 0.3125, SE = 0.2925, t(88) = 1.069, p = 0.2883) and prior VR experience (b = −0.1774, SE = 0.2558, t(88) = −0.6935, p = 0.4899) did not significantly predict environmental self-identity. On the other hand, a marginally negative effect of cybersickness on environmental self-identity was found (b = −0.2703, SE = 0.1424, t(88) = −1.898, p = 0.0611). However, the interaction between condition and cybersickness was not significant (b = 0.2180, SE = 0.1919, t(88) = 1.136, p = 0.2591).

For Study 2, the analysis included data from 97 participants. The overall model accounted for 11.35% of the variance in environmental self-identity (R2 = 0.1135, F(5, 91) = 2.3309, p = 0.0486).

Similar to Study 1, condition (b = −0.5018, SE = 0.5593, t(94) = −0.8972, p = 0.3720), gender (b = −0.1864, SE = 0.2585, t(94) = −0.7213, p = 0.4726) and prior VR experience (b = 0.2236, SE = 0.2553, t(94) = 0.8758, p = 0.3834) did not significantly predict environmental self-identity.

However, both cybersickness (b = −0.2808, SE = 0.1421, t(94) = −1.9758, p = 0.0512) and the interaction between condition and cybersickness (b = 0.4198, SE = 0.1903, t(94) = 2.2056, p = 0.0299) was significant.

Post-hoc analyses indicated that the conditional effect of condition on environmental self-identity varied significantly at different levels of cybersickness. Specifically, at the 84th percentile of cybersickness (score of 4), the effect of condition on environmental self-identity was significant (b = 1.1773, SE = 0.3598, t(94) = 3.2725, p = 0.0015).

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

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