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Encouraging pro-environmental behaviour in a virtual reality serious game: the interplay between competition and prior knowledge

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ABSTRACT

Drawing upon self-determination theory, this study investigates whether the effects of competition interact with individuals' prior knowledge to influence the motivations for and antecedents to their pro-environmental behaviour. Using a virtual reality serious game about plastic waste, we conducted a 2 (Game environment: Competition vs. Non-competition) × 3 (Prior knowledge about plastic waste: Low vs. Medium vs. High) between-subjects experiment with 61 participants ($M_{age} = 23.31$, $SD_{age} = 2.77$). Results indicated that competition had differential impacts depending on individuals' prior knowledge. Competition had negative effects on motivation and antecedents to pro-environmental behaviour for players with low levels of prior knowledge and positive effects for players with medium levels of prior knowledge. As the first study to investigate prior knowledge as a moderator for the effects of competition in a virtual reality serious game, our research contributes to the literature by clarifying the conditions under which competition could promote pro-environmental behaviour and offers suggestions on customised use of competition for communication practitioners.

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Virtual reality; serious games; pro-environmental behaviour; self-determination theory; prior knowledge

1. Introduction

The potential of virtual reality (VR) for encouraging pro-environmental behaviours is a long-standing preoccupation of both academics and practitioners. Well before the mainstreaming and commercialisation of VR, scholars (e.g. Taylor and Disinger 1997) lucidly described how VR could be a beneficial tool for environmental education by facilitating interactive and experiential learning opportunities. Recently, VR has been widely regarded as an innovative approach for raising awareness about critical environmental issues through immersive storytelling and exposure to novel experiences (Markowitz and Bailenson 2021). In particular, VR serious games have been gaining substantial interest as novel platforms for encouraging pro-environmental knowledge, attitudes, and behaviours (Cho and Park 2023; Lo and Tsai 2022; Sajjadi et al. 2022; Stenberdt and Makransky 2023). For example, Markowitz et al. (2018) reported positive knowledge gain and increased interest in learning about ocean acidification after participants were exposed to an immersive VR experience.

Serious games are defined as games designed to confer knowledge while encouraging engagement in active learning (Mestadi et al. 2018). Serious games are different from other forms of environmental education as they enable active learning by supporting players' independent decision-making in and control over various scenarios (Cooke, Dusenberry, and Robinson 2020; Westera 2019). Through these processes, serious games can foster players' motivation to learn about and engage in pro-environmental behaviours in a more efficient way (Cooke, Dusenberry, and Robinson 2020). Serious games aimed at environmental education are additionally distinct from other educational topics. Beyond conveying knowledge, serious games with environmental education goals also aim to shape players' pro-environmental attitudes and behaviours (Cho and Park 2023).

Media technologies like VR are expected to be complementary platforms for serious games as they can promote greater immersion in authentic environments, encourage exploration, and increase enjoyment (Pacheco-Velázquez, Salinas-Navarro, and Ramírez-

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Montoya 2023; Sherman and Craig 2003). VR's unique affordances—such as how VR devices provide seamless interaction with serious games—can also enhance players' perception of gamefulness, or their perception of being engaged in a game-like activity (Deterding 2015). Literature has further found VR serious games to facilitate the immediate transfer of behavioural skills from VR to the real world (Checa and Bustillo 2020).

However, scholarship on serious games sees much disagreement over how the games should be designed. Importantly, serious games should maintain a balance between elements that provide gamefulness and those that support knowledge transfer, attitude change, or behaviour change (Giessen 2015; Ravyse et al. 2017). A prominent game design element that is consistently entangled in this gamefulness–learning predicament is competition. Competition in serious games is frequently operationalised as a feature that reveals to players how well they have performed compared to others, such as in the form of rankings (Cagiltay, Ozcelik, and Ozcelik 2015). While some may suggest that competition is an influential factor in stimulating gameplay by enhancing players' interest and engagement, competition may also induce anxiety or serve as a distraction that can negatively impact learning (Hwang, Wu, and Chen 2012; Ravyse et al. 2017; Urdan and Schoenfelder 2006). Scholars have also observed that competition produces inconsistent outcomes across different contexts, game genres, player pre-dispositions, and learning outcomes (Chen, Law, and Huang 2019; Delemere and Liston 2024; Xiong et al. 2024).

Likewise, some scholars exploring the effects of competition on learning in VR have identified the game element to be beneficial, playful, fun, and gameful (e.g. Du, Fan, and Yang 2020) while others suggest that competition induced stress and had negative effects on knowledge acquisition (e.g. Liang et al. 2019). However, there are notable limitations with these studies; for example, the different operationalizations of competition as a multiplayer game (vs. a single-player game; Du, Fan, and Yang 2020) or as a between-pair competition (vs. between-pair collaboration; Liang et al. 2019) restricts comparison across studies. Moreover, these studies varied in how they evaluated the underlying effects of competition on VR serious games, whether through assessments of specific gameplay achievements (Liang et al. 2019) or through real-world learning outcomes and motivation (Du, Fan, and Yang 2020). Lastly, previous research, such as that by Du, Fan, and Yang (2020) and Liang et al. (2019), has examined the impact of competition in digital learning environments, but these studies primarily focused on multiplayer dynamics or collaborative environments. In contrast, this study investigates competition within a solitary VR serious game and introduces prior knowledge as a moderator, which was not considered in these previous studies. The emphasis on individual differences such as prior knowledge as a moderator allows for a more nuanced understanding of how competition affects motivation and learning outcomes, filling a critical gap in the literature.

Uncertainty over the inclusion of competition in learning environments is not a concern unique to serious games. Past research has documented variability in the effects of competition across various digital learning environments, such as game-based learning contexts (Chen, Law, and Huang 2019; Ho, Hung, and Kwan 2022; Licorish et al. 2018) and when using educational technology (Chen et al. 2020a; Worm and Buch 2014; Yu 2016). Notably, studies from these fields often observe dissonance between theory and empirical findings. Specifically, self-determination theory (SDT)—one of the most frequently adopted theories to understand the psychological processes underlying motivation and behaviour change (Hammady and Arnab 2022; Krath, Schürmann, and von Korflesch 2021)—suggests that competition may be detrimental to learning (Deci, Koestner, and Ryan 1999; Kaplan and Madjar 2015). Yet, other studies have contrarily demonstrated the positive effects of competition on motivation and learning outcomes (e.g. Ho, Hung, and Kwan 2022; Liu et al. 2022; Zhou, Lin, and Mou 2023).

In view of the inconsistent study and outcomes of competition, as well as the tendency for serious games for environmental education to utilise elements of competition (Boncu, Candel, and Popa 2022), this study aims to obtain a more nuanced understanding of the conditions under which competition in a VR serious game can support or deny pro-environmental learning goals. Considering environmental education's aim to influence pro-environmental attitudes and behaviour (Cho and Park 2023), we quantify learning outcomes as the improvement of relevant antecedents to pro-environmental behaviour (A-PEB; i.e. self-efficacy, environmental locus of control, attitude, and behavioural intention regarding pro-environmental practices). We employ SDT as a structured approach for investigating how competition may influence A-PEB. Importantly, SDT offers a theoretically grounded rationale for the negative effects of competition on learning and behaviour (Deci, Koestner, and Ryan 1999).

While SDT has been widely applied in various educational settings to understand the effects of competition and motivation, there is a paucity of research on how context-specific factors such as prior knowledge influence these relationships. This study addresses this gap by investigating the interaction between competition and prior knowledge in a VR-based serious game. The results suggest that prior knowledge can moderate the effects of competition on psychological needs and other downstream consequences, thus providing new insights into how SDT principles can be applied to different learning contexts.

2. Study context and objectives

For this study, we developed a VR serious game about reducing plastic consumption and managing plastic waste. We note that plastic waste is increasingly recognised as a serious global environmental concern (United Nations Environment Programme 2021; World Economic Forum 2020) and that there is a growing impetus to mobilise public action to address issues related to plastic consumption. However, while public awareness of plastic use and its associated effects on the environment and human health is high, individuals still lack the motivation to reduce their plastic consumption (Smith and Brisman 2021). As such, our VR serious game aims to convey scientifically accurate facts about plastic waste and illustrate the actions individuals can take to reduce plastic consumption. We adopt an experimental approach to investigate how competition in VR serious games influences two key aspects of the environmental education process: motivation and A-PEB.

By doing so, this paper responds to two key needs in extant literature on serious games: first, we address and seek an explanation for the inconsistent effects of competition on motivation and behaviour in serious games (Ravyse et al. 2017; Sailer and Homner 2020). Competition currently occupies an ambiguous position in serious game research; it is simultaneously regarded as a quintessential characteristic of serious games (Cagiltay, Ozcelik, and Ozcelik 2015) and is thought to be detrimental to the education process from a theoretical standpoint. By elucidating the impacts of competition in serious games, this study's findings would be further applicable to SDT-based research on competition in other learning contexts.

Second, recognising the variability of competition's influence on motivational and behavioural outcomes across different contexts, we investigate its efficacy within the relatively novel context of a VR serious game about plastic waste (Chen, Law, and Huang 2019). This is especially salient as the demand for more engaging and immersive platforms for environmental education increases (Dunn, Shah, and Veríssimo 2021; Morganti et al. 2017). As such, the results of this study will inform VR serious game developers about which game elements can support motivation and relevant A-PEB.

3. Literature review

3.1. Self-determination theory

SDT (Ryan and Deci 2000, 2022) argues that motivation can be classified into different types depending on how autonomous, as opposed to controlled, the motivation is. On one end of the SDT continuum sits intrinsic motivation, the most autonomous type of motivation, while on the other end sits external regulation, the most controlled type of motivation. When individuals find tasks inherently enjoyable, they are intrinsically motivated to undertake these tasks (Osbaldiston and Sheldon 2003; Ryan and Deci 2000). Conversely, when individuals participate in tasks governed by external sources of control (e.g. reward or punishment), they become extrinsically motivated (Pelletier et al. 1998). Scholars have found intrinsic motivation and more autonomous forms of extrinsic motivation to be positively associated with the conduct of various pro-environment behaviours (Barszcz et al. 2022; Cooke, Dusenberry, and Robinson 2020; de Groot and Steg 2010; Lavergne et al. 2010; Mahmud, Husnin, and Tuan Soh 2020). Hence, inducing individuals' autonomous motivation is important for serious games designed for environmental education.

SDT contends that human motivation is subject to the influence of social-contextual factors (e.g. feedback and rewards; Ryan and Deci 2000). When these factors contribute to the fulfilment of individuals' fundamental psychological needs during an activity, autonomous motivation in the activity can be facilitated. The two most important psychological needs associated with autonomous motivation are autonomy and competence. Autonomy describes the feeling that one's action or inaction is driven by reasons internal to the self (Decharms and Carpenter 1968) while competence is defined as the propensity to interact effectively with the environment and confidence in achieving desired outcomes (Edmunds, Ntoumanis, and Duda 2008). In the context of gaming, Ryan, Rigby, and Przybylski (2006) found that autonomy and competence need satisfaction were both positively associated with game enjoyment, a measure of intrinsic motivation. In the context of environmental education, Cooke, Dusenberry, and Robinson 2020) found that perceived autonomy was the most important predictor of autonomous motivation to enact pro-environmental behaviours.

While relatedness—the sense of belonging and meaningful connection to other social figures—is also a psychological need that is associated with autonomous motivation, it is not relevant to our present context of a single-player VR serious game. Within games research, relatedness is relevant when there are elements of social interaction, such as within multiplayer games or when players may interact with computer-driven non-player characters (NPCs; Ryan, Rigby, and Przybylski 2006; Uysal and Yildirim 2016). As the VR game we developed does not include any meaningful social interaction due to resource-based limitations, we excluded relatedness for this study; this practice follows previous studies that did not manipulate game features for social interaction (e.g. Peng et al. 2012).

SDT has been widely utilised to examine the motivational dynamics of gaming and gamified environments, shedding light on how elements such as autonomy, competence, and relatedness shape player experiences and outcomes. Although significant progress has been made in understanding these dynamics, most studies have focused on entertainment-oriented online games, often overlooking how SDT can be applied in serious games, particularly those designed to promote pro-environmental behaviours. This study addresses this gap by examining the influence of competition in a virtual reality (VR) serious game, exploring the role of prior knowledge as a moderator to provide nuanced insights into how competitive elements interact with individual differences in shaping motivation and behaviour.

Existing research has highlighted the complexity of competition's impact on player motivation, suggesting that it can both enhance and undermine engagement depending on the context. For instance, Lee, Chang, and Li (2024) found that competition in online games can increase extrinsic motivation but may also lead to problematic behaviours such as game cheating if players perceive the competitive elements as undermining their autonomy or competence. This nuanced view of competition is further supported by findings from T'ng, Ho, and Pau (2023), who demonstrated that players experiencing frustration of their psychological needs were more likely to develop maladaptive gaming behaviours, and competition motive served as a mediator in the relationship. Such studies emphasise that competition's effects are not uniform and are contingent upon the satisfaction or frustration of psychological needs. However, research in this area has primarily focused on the detrimental effects of competition in traditional gaming contexts, with little attention given to its role in serious games aimed at educational or behavioural outcomes.

In contrast, recent studies have shown that competition can have positive effects on motivation when it aligns with players' psychological needs and personal characteristics. For example, Qian et al. (2022) found that relatedness, achieved through social interactions and competition in esports, was a significant predictor of player engagement and long-term commitment. Similarly, Türkay highlighted that during the COVID-19 pandemic, video games served as compensatory tools that helped players fulfil their needs for autonomy, competence, and relatedness. These findings suggest that competition can promote positive behaviours and engagement when it aligns with players' intrinsic motivations and psychological needs. However, this positive effect may vary based on individual differences such as prior knowledge, which has not been adequately explored in the context of VR serious games.

Moreover, the role of prior knowledge in moderating the effects of competition on motivation remains under-theorised. Prior knowledge, akin to competence in the SDT framework, influences how individuals perceive and respond to external motivators such as competition. As shown by Tsai (2021), enhancing players' perceived competence through real-time feedback in a gamified exercise platform resulted in increased motivation and engagement. Applying this understanding to a VR serious game, it can be hypothesised that players with higher levels of prior knowledge will experience competition as less threatening to their autonomy and competence, thereby enhancing their intrinsic motivation and behavioural intention. In contrast, players with lower levels of prior knowledge may perceive competition as undermining their competence, leading to demotivation or disengagement.

The present study aims to contribute to the literature by investigating how competition interacts with prior knowledge to influence motivation and pro-environmental behaviours in a VR serious game. While previous research (Huang 2022) has demonstrated the efficacy of gamification elements such as competition in promoting pro-environmental behaviour, these studies have not considered how individual differences in prior knowledge might alter these effects. By introducing prior knowledge as a moderator, this study extends the application of SDT in serious games and offers practical implications for the design of gamified systems that effectively engage diverse audiences.

The exclusion of relatedness in this study is justified by the solitary nature of the VR game used. In contrast to multiplayer games where social interactions are pivotal, VR serious games often do not provide the social contexts necessary for fulfilling relatedness needs. Previous studies have shown that relatedness is a significant predictor of motivation and engagement in multiplayer settings (Reer and Krämer 2020), but its absence does not necessarily undermine motivation in single-player contexts where autonomy and competence are the primary drivers. Therefore, the current study focuses on the interplay between autonomy, competence, and prior knowledge, and how these factors influence motivation and behaviour in a VR serious game.

This study contributes to the ongoing discourse on competition in gamified systems by emphasising the importance of aligning competitive elements with individual characteristics such as prior knowledge. By integrating insights from the literature, this research addresses the gaps identified by previous studies and provides a comprehensive understanding of how competition influences motivation and pro-environmental behaviours in serious games.

SDT served as the foundational theoretical framework guiding both the conceptualisation and operationalisation of variables in this study. SDT posits that three basic psychological needs—autonomy, competence, and relatedness—are essential for fostering intrinsic motivation and optimal functioning. These needs are central to understanding how different game elements, such as competition, impact player motivation and behavioural outcomes. In this study, the research model was developed to specifically explore how competition interacts with prior knowledge to influence these psychological needs and downstream motivational outcomes in a VRserious game context.

The research model was constructed based on the premise that competition, a prominent game design element, can either support or thwart players' psychological needs, leading to differential motivational outcomes. Specifically, the study hypothesised that prior knowledge would moderate the impact of competition on the satisfaction of autonomy and competence needs, which in turn would influence autonomous motivation and pro-environmental behavioural intentions.

3.2. Effects of competition

According to SDT, competition is thought to diminish individuals' sense of autonomy which, in turn, harms the development of autonomous motivation (Deci, Koestner, and Ryan 1999). In a classic study, Deci et al. (1981) invited experiment participants to play a puzzle game and found that those instructed to compete with other players showed lower intrinsic motivation in the activity than those instructed to perform as well as they could. The results can be attributed to the controlling effect of competition (Urdan and Schoenfelder 2006). As such, researchers have warned against the use of competition and social comparison if one hopes to create a conducive educational environment that supports individuals' needs for autonomy (Kaplan and Madjar 2015). The importance of autonomy fulfilment is also acknowledged by a systematic review that analysed 56 papers on the use of serious games for environmental communication which concluded that for a game to be effective, the game design should support players' psychological needs for autonomy (Tan and Nurul-Asna 2023). The studies above suggest that adding a competitive element to a serious game would negatively impact learners' autonomous motivation and related behavioural outcomes.

In addition to constructs commonly studied within or adjacent to SDT research like autonomy and autonomous motivation (i.e. the motivational outcomes), this study also seeks to explore the effects of competition on various antecedents to pro-environmental behaviour (A-PEB)—recognising A-PEB as necessary outcomes of a serious game for environmental education (Cho and Park 2023). Relevant A-PEB that we choose to focus on are the acquisitions of pro-environmental self-efficacy (Sawitri, Hadiyanto, and Hadi 2015), environmental locus of control (Cleveland, Kalamas, and Laroche 2005), attitude (Ajzen 1991), and behavioural intention regarding plastic waste and consumption (Liu, Teng, and Han 2020). Self-efficacy refers to the degree of confidence that one possesses with respect to a given pro-environmental behaviour (Yuriev et al. 2020) while environmental locus of control relates to one's perceptions of their obligations toward and abilities to influence pro-environmental outcomes (Cleveland, Kalamas, and Laroche 2005). Given the context of the present study, we chose to assess two attitudinal variables—namely, attitude toward reducing plastic waste and attitude toward learning about plastic waste reduction.

These variables have been assessed as desirable outcomes in prior research on serious games with pro-environmental narratives (Boncu, Candel, and Popa 2022; Wang and Yao 2020) and have been regarded as the key determinants of pro-environmental behaviour (Bamberg and Möser 2007; Hines, Hungerford, and Tomera 1987). Specifically, these variables correspond with the model of responsible environmental behavior[1] (Hines, Hungerford, and Tomera 1987), with the exception of pro-environmental self-efficacy. Nevertheless, self-efficacy was included as it is 'arguably the most popular form of expectancy belief in the applied psychology literature' (Judge et al. 2007, 107) and recognized as an important predictor of pro-environmental behaviour across various contexts (e.g. Morren and Grinstein 2016; Tabernero and Hernández 2011; Yuriev et al. 2020).

While few studies have assessed the direct impact of competition on A-PEB, past research has identified that competition (vs. cooperation) can induce individuals to partake in less environmentally friendly behaviours (Cuadrado et al. 2017). Research exploring gamified interventions for improving pro-environmental behaviour has also cautioned against centring competitive elements as these might be antithetical to the altruistic nature of such pro-environmental interventions (Wang and Yao 2020). When it came to individuals' environmental locus of control, previous research has found that competitive gamified interactions do not significantly influence their sense of responsibility for affecting pro-environmental outcomes when compared to those that are cooperative (Cao and Liu 2022). Furthermore, the authors suggest that competitive interactions stimulate attention toward motivations not directly related to pro-environmental outcomes, like social gain. As van der Linden (2015) argues, although competitive interventions may help raise awareness for pro-environmental issues, competitions are inherently driven by extrinsic motivation toward behaviours that benefit one's self-interest and do not encourage lasting pro-environmental behaviour. In contexts outside of environmental education, scholars have additionally noted the detrimental effects of competition on self-efficacy (Chan and Lam 2008) and attitudes toward learning (Ke 2008)

As such, we follow that SDT generally posits the negative effects of competition on learning outcomes (Ryan and Deci 2016), which in this case, refers to A-PEB. We therefore hypothesise:

> H1: Competition (vs. non-competition) has a negative effect on (a) autonomy, (b) autonomous motivation, (c) pro-environmental self-efficacy, (d) environmental locus of control, (e) attitude, and (f) behavioral intention to mitigate the issue of plastic waste.

3.3. Competing evidence on the effects of competition

As discussed in the introduction, some empirical evidence that does not leverage SDT has suggested that competition may occasionally have a positive effect in serious games. Many studies have identified the positive effects of competition on motivational and learning outcomes (e.g. Ho, Hung, and Kwan 2022; Liu et al. 2022; Zhou, Lin, and Mou 2023). For example, some research shows that competition could enhance learners' motivation (Cagiltay, Ozcelik, and Ozcelik 2015; Wang 2015) and desirable pro-environmental behaviour (Zhou, Lin, and Mou 2023). Scholars have also reported that competition could increase individuals' interest, enjoyment (Plass et al. 2013), and engagement (Cheng et al. 2009) while playing a serious game. It should be noted that while these studies did not employ SDT, these three factors can be seen as indicators of intrinsic motivation (Ryan and Deci 2000). Cognitively, some scholars suggest that competition could serve to focus individuals' attention and produce better learning outcomes (e.g. Cheng et al. 2009).

To reconcile the inconsistent findings, scholars suggest that the effects of competition might be moderated by other variables (Chen, Law, and Huang 2019). A meta-analysis (Chen, Shih, and Law 2020b) of 25 articles on digital game-based learning showed that the subject area to be learned (e.g. math, language, social sciences), age of participants, and game type (e.g. strategy, role-playing, action games) moderated the effects of competition in such games on learning. Additionally, some individual differences may also moderate the effects of competition. To illustrate, Song and colleagues (2013) revealed significant interaction effects between competition and competitiveness as a personality trait. Specifically, the authors found that in the context of an exercise game, competition and intrinsic motivation were negatively associated only among individuals with a less competitive personality. Among the more competitive participants, competition was positively associated with intrinsic motivation (Song et al. 2013).

In gamification research, the presence of various individual or contextual factors that influence the motivational pull of game elements like competition are often referred to as situated motivational affordances (Deterding 2011). Deterding (2011) contends that game elements that support the fulfilment of motivational outcomes are dependent on not only the affordances of the game element, but also the abilities of the player and the contextual environment that the game element is deployed in. For example, leaderboards are a game element frequently used to motivate learning through encouraging competition. Yet, the motivational effects of leaderboards are conditional on several factors, such as the player's need for achievement or whether the leaderboard rankings have actual rewards or consequences. The current study thus aims to investigate the role of an underexplored individual difference, prior knowledge, as another potential moderator for the effects of competition on motivation and A-PEB.

3.4. Effects of competition contingent on prior knowledge

3.4.1. Motivational outcomes

As stated in our discussion of SDT and competition, some scholars believe that competition and the associated social comparison are detrimental to learning because they thwart individuals' needs for autonomy

(Kaplan and Madjar 2015). However, people are not always passive recipients of environmental influences. In the face of threats, they may engage in approach coping, where they attempt to directly tackle and minimise the effects of external threats on them, or avoidance coping, where they relinquish their power to fight against the threats by disengaging from them (Roth and Cohen 1986). In the same vein, research has shown that when individuals are deprived of psychological needs by contextual factors, they may act against those factors to restore their internal states (Fiske 2018; Maslow 1943; Veltkamp, Aarts, and Custers 2009), which is equivalent to approach coping. This implies that competition may not harm individuals' sense of autonomy insofar as individuals are able to engage in autonomy restoration processes.

While relevant research in the context of SDT is limited, extant empirical evidence suggests that only when individuals perceive themselves as competent in the target task will they act to restore their autonomy. That is, individuals' perceived task competence can weaken the negative effects of competition on autonomy. Specifically, Radel and colleagues (2013) found that when individuals received threats to their perceived autonomy before playing a computerised game, only individuals with prior experience (i.e. more competent) relevant to the task engaged in autonomy restoration behaviours. As for individuals without prior experience (i.e. less competent), they not only failed to act to restore their autonomy but also reacted to the experimental treatment in a way that further undermined their autonomy (Radel, Pelletier, and Sarrazin 2013). Similar results were found when the authors manipulated research participants' perceived competence in the task directly. The results suggest that high perceived competence could protect individuals from the negative influence of autonomy threats by motivating autonomy restoration behaviours. In contrast, individuals with low perceived competence are particularly vulnerable to autonomy threats. These findings echo prior research that associates high competence with approach coping and low competence with avoidance coping (Lazarus 1993).

In Radel and colleagues' (2013) study, the authors operationalised competence as prior experience with the target task because their task was skill-based, where performance was expected to improve with more practice. In this current study, given that our task is knowledge-based (i.e. the more knowledge individuals have about plastic waste, the better their performance in the VR game), we operationalise task competence as individuals' level of prior knowledge about plastic waste and consumption. Based on the arguments and findings presented above, we believe that the effect of competition on autonomy may depend on individuals' efforts to restore their autonomy, which may be influenced by their prior knowledge. In other words, we argue that high prior knowledge about plastic waste can weaken the negative effects of competition on autonomy, while low prior knowledge about plastic waste can exacerbate the negative effects of competition on autonomy. We posit:

> H2: Prior knowledge moderates the effect of competition (vs. non-competition) on autonomy, such that the negative effect of competition on autonomy will be weaker for participants with high prior knowledge compared to those with low prior knowledge.

Given the strong connection between the psychological need for autonomy and autonomous motivation as posited by SDT (Ryan and Deci 2000), individuals' autonomous motivation tends to increase when their autonomy is supported. According to SDT, autonomous motivation flourishes in environments where individuals feel that their actions are self-directed and aligned with their personal values and interests. As autonomy-supportive environments foster this sense of self-determination, they are positively associated with higher levels of autonomous motivation (Patall, Sylvester, and Han 2014). Conversely, environments perceived as controlling or limiting autonomy can undermine autonomous motivation.

Building on H2, which hypothesises that competition may have a more detrimental impact on autonomy for individuals with high prior knowledge, it follows that this negative effect should extend to autonomous motivation as well. When individuals possess high prior knowledge, they may feel more confident in their expertise, making competition feel more controlling or restrictive, as it imposes external pressures that conflict with their internal sense of competence and self-direction. This dynamic may diminish their sense of autonomy and, in turn, reduce their autonomous motivation to engage in the task. In contrast, individuals with lower prior knowledge might be less sensitive to the autonomy-reducing aspects of competition, as they may focus more on learning and improvement rather than on external validation.

Thus, the moderation effect hypothesised in H2—where competition is expected to have a stronger negative impact on autonomy for those with high prior knowledge—should similarly manifest in the context of autonomous motivation. Specifically, when competition undermines feelings of autonomy, it is likely to reduce autonomous motivation more significantly for individuals with low prior knowledge compared to those with high prior knowledge. Hence, we posit:

H3: Prior knowledge moderates the effect of competition (vs. non-competition) on autonomous motivation, such that the negative effect of competition on autonomous motivation will be stronger for participants with high prior knowledge compared to those with low prior knowledge.

3.4.2. Antecedents to pro-environmental behaviour (A-PEB)

In the context of pro-environmental behaviours, high levels of prior knowledge may also act to override the negative effects of competition. For example, Cuadrado et al. (2017) identified that participants with greater knowledge about environmental problems (i.e. students of environmental sciences vs. students of educational sciences) were able to counteract the negative effects that competition had on pro-environmental behaviour. Moreover, insights from the cognitive load theory (CLT; Sweller 2011) and the flow theory (Csikszentmihalyi 2009) also suggest that competition may disproportionally affect the learning, and thus behavioural, outcomes of individuals with low prior knowledge.

CLT postulates that a person's cognitive capacity is limited; when cognitive demand exceeds one's cognitive capacity, one's processing efficiency would be undermined (Sweller 2011). Research has shown that individuals learn more efficiently when they have prior knowledge of the content to be learned, such that subsequent learning is less cognitively demanding for them than for those without prior knowledge (Dong, Jong, and King 2020; Mihalca et al. 2011; Sasupilli and Bokil 2022). Competition increases learners' cognitive load, which refers to the burden on their working memory (Chang and Yang 2023), as it constitutes an additional element that demands processing beyond the learning task (Nebel, Schneider, and Rey 2016). Given individuals' limited cognitive capacity (Sweller 2011), the extra cognitive load introduced by competition would reduce learners' cognitive resources that could otherwise be dedicated to learning. While individuals with high prior knowledge might be protected against such pernicious effects of competition on learning due to their learning efficiency, the learning outcomes of those with low prior knowledge are likely to be negatively affected when they learn in a competitive environment. Empirical research on serious games has also found that individuals with low prior knowledge are more vulnerable to distractions by environmental factors that are not central to the learning task (Yeo et al. 2022), which could lead to poorer learning outcomes.

Alternatively, flow theory suggests that individuals could achieve the state of flow, an optimal experience of immersion and concentration conducive to learning, when the challenges they face while learning match their skills to tackle the challenges (Csikszentmihalyi 2009; Li et al. 2021). In the context of educational games, scholars suggest that flow experiences are achieved when players can effectively apply their knowledge and skills in the gaming environment (Kiili et al. 2012). Consequently, when the challenges exceed one's skills (i.e. prior knowledge), one experiences anxiety that may impinge on their effective acquisition of positive learning outcomes (Csikszentmihalyi 2009). Alternatively, competition can also make a serious game more challenging (Burguillo 2010), which might make individuals with low prior knowledge feel anxious (Urdan and Schoenfelder 2006) since their perceived skills are below the challenge level of the game, resulting in poorer learning outcomes. Based on the arguments proposed by CLT and flow theory, we therefore hypothesise that high prior knowledge about plastic waste can weaken the negative effects of competition on the learning outcomes relevant to our VR serious game—A-PEB (i.e. self-efficacy, environmental locus of control, attitude, and behavioural intention regarding pro-environmental practices)—while low prior knowledge about plastic waste can exacerbate the negative effects of competition on A-PEB. Hence, we hypothesised:

H4: Prior knowledge moderates the effects of competition (vs. non-competition) on learning outcomes, including (a) pro-environmental self-efficacy, (b) environmental locus of control, (c) attitude, and (d) behavioral intention to mitigate plastic waste. Specifically, the negative impact of competition on these learning outcomes will be stronger for participants with higher prior knowledge compared to those with lower prior knowledge.

4. Method

4.1. Participants

We recruited 67 undergraduates aged 21 and above from a Singapore university to participate in our research. Participants initially completed a pre-test survey that measured their prior knowledge about plastic waste and captured their demographic information. Two weeks later, participants were invited to the laboratory to play a VR game about plastic waste. They were randomly assigned to either the competition condition or the non-competition condition and played a version of the game designed for their assigned condition. After playing, participants completed a post-test survey that measured our dependent variables of interest. After excluding participants who failed the attention check questions in the post-test survey, we had a final sample of 61 participants for data analysis. Participants' ages ranged from 21 to 34 ($M = 23.31$, $SD = 2.77$) and 59% ($N = 36$) were female. The majority of participants were Singapore citizens (77%, $N = 47$) or permanent residents of Singapore (6.6%, $N = 4$). For ethnicity, most participants were Chinese (83.6%, $N = 51$). Participants were compensated with either SGD10 in cash or five course credits by choice. This study was approved by the university's Institutional Review Board (Reference Number: IRB-2022-885).

A power analysis was conducted to assess whether the sample size was adequate to ensure the validity of test outcomes. Previous meta-analyses (e.g. Rutten, Van Joolingen, and Van Der Veen 2012) indicate that the effects of immersive-world conditions in digital devices on learning outcomes are large, with Cohen's $d = 1.39$ (Cohen's $f = .70$). Based on these findings, we conducted a G*Power analysis with $\alpha = 0.05$, power = 0.80, and Cohen's $f = .70$, determining that a minimum sample size of 33 participants would be sufficient to detect medium-to-large effects. Our sample size of 61 not only meets but exceeds this requirement, providing adequate power to test our hypotheses effectively. Although larger sample sizes can enhance statistical power, a sample of 61 is still sufficient to detect medium-to-large effects (Cohen 1992). Therefore, we are confident that this sample size enables the study to detect meaningful differences without necessitating an excessively large sample.

4.2. Materials and design

To address our proposed hypotheses, we developed an educational VR game focused on plastic waste reduction in Singapore. Early versions of the game were pre-tested with users and the final stimulus was refined based on participants' feedback. The game featured everyday scenarios where participants made choices that could either mitigate or exacerbate the issue of plastic waste. Each choice made earned players points corresponding to the environmental impact of that decision, with higher points awarded to choices that were more environmentally friendly. The points attributed to each choice were determined based on a simplified life cycle assessment, a method used to assess the environmental impact of a given product throughout its life cycle, encompassing the production of its constituent raw materials, the manufacturing of the product, and how it is used and disposed of (Muralikrishna and Manickam 2017).

A globe was present throughout the VR game as a point-tracking mechanism (see Figure 1). When participants made a choice that earned them more points, the globe would flash green. Conversely, when participants made a choice that earned them fewer points, the globe would flash red. The overall impact of participants' choices was depicted through the final scene in the VR game: an underwater environment that varied depending on the points participants scored. The best outcome featured a bright underwater environment populated with ocean flora and fauna, while the worst outcome featured a dull underwater environment devoid of life (see Figure 2).

We designed two versions of the VR game according to the conditions delineated by our proposed hypotheses: competition and non-competition. In the competition condition, participants viewed a pre-populated leaderboard (see Figure 3) after each scene within the VR game, displaying their own and the alleged competitors' scores. In the non-competition condition, participants were not shown a leaderboard in the game.

4.3. Experimental procedure

Upon arriving at the laboratory, each participant was led to a room where they first read a study information sheet and signed a consent form. Participants were then taught how to operate the VR controllers and were given written instructions about the VR game.

The instruction sheet briefed the participants about the tasks they were to perform in the game, the point-tracking mechanism, and the possible outcomes for the final scene. Participants in the competition condition were told that they would be competing against five other players who had previously completed the game and that their points and ranking would be displayed on a leaderboard throughout the game. To further manipulate participants' sense of competition, we adapted instructions from prior research (Deci

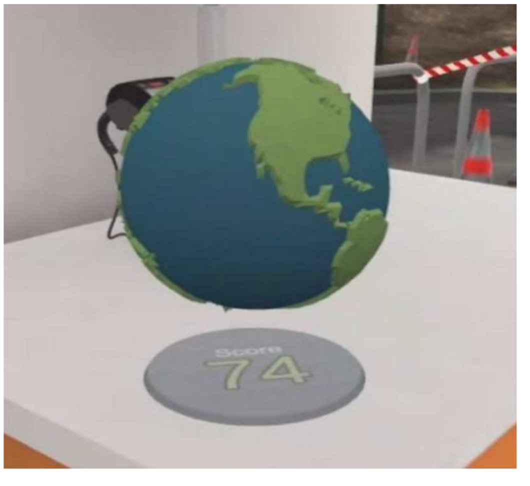

Figure 1. Globe in the VR game.

Figure 2. Underwater scenes for participants with high points (Left), medium points (Middle), and low points (Right).

et al. 1981; Song et al. 2013). In the form of both written and verbal instructions, participants in the competition condition were asked to 'score more points than the other players' on the leaderboard, while those in the non-competition condition were asked to 'try to score as many points as you can.' To align our experimental manipulation with prior studies (e.g. Deci et al. 1981; Song et al. 2013), we asked participants in the non-competition group to score as many points as they could, instead of mentioning nothing about point scoring. Our manipulation check showed that this manipulation was successful. Specifically, participants in the competition condition scored significantly higher than those in the non-competition condition on items measuring their sense of competition (see Section 4, results).

We also designed a set of instructions, based on past research (Sheldon and Filak 2008), given verbally by experiment facilitators to all the participants to create a need-supportive environment before participants played the game. To support their need for autonomy, we asked participants to try their best to navigate the game by themselves as much as possible and told them that they would learn quickly as they proceeded. To support their need for competence, we asked participants to make choices in the game that they thought would be the best for the environment. While explicitly telling the participants to make choices that are good for the environment risked introducing demand characteristics, since participants in both conditions received this instruction, they would be subject to the same pressure of social desirability, if any. Hence, any difference in participants' performance scores between the two groups would still unbiasedly reflect the effects of competition.

After detailed instructions, participants played the VR game using a Meta Quest 2 headset. The game featured four everyday scenarios where participants had to make choices that had different environmental impacts.

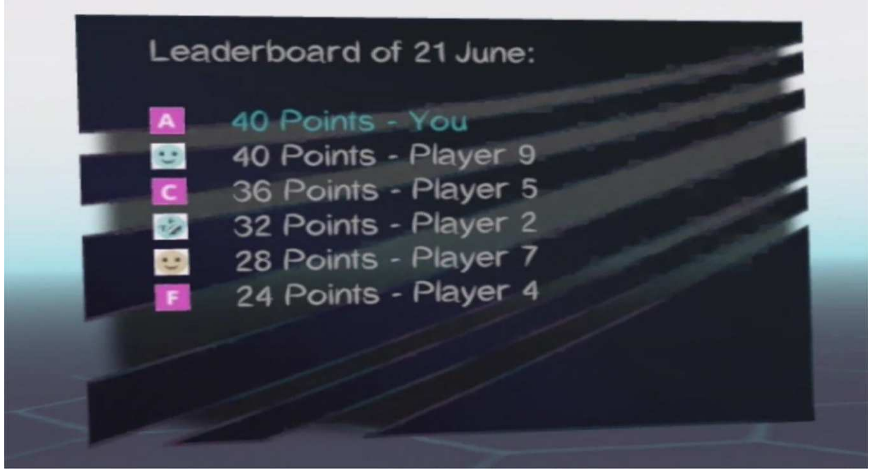

Figure 3. Pre-populated leaderboard in the competition condition.

In the first scenario, participants were told via instructions on a tablet and audio narration that they would be completing a series of tasks: getting some food at the hawker centre (open-air food courts common in Singapore), shopping for groceries at the supermarket, and ending the day at home. Before embarking on these tasks, participants were instructed to bring out a bag, container, bottle, and straw. They could then either choose between three options for each item, each of a different material, or choose not to bring that item with them. For example, participants could choose to either bring a single-use plastic bag, a multiple-use cotton bag, a multiple-use plastic bag, or no bag.

The second scenario required participants to buy food and a drink at a hawker centre. For both the food and the drink, participants could either choose to dine-in and use the store's crockery, get take-out using the container, bottle, and straw selected in the first scenario, or get take-out using single-use plastic options.

In the third scenario, participants were prompted to select four items at the supermarket: eggs, meat, bananas, and carrots. Each item had several packaging options that either used plastic, an alternative material, or had no packaging. For example, participants could choose between selecting bananas that were pre-packaged in plastic, packed with a paper banding, or that did not have any packaging. Afterward, participants could choose either to bag the bananas with an additional single-use plastic bag or not to use an additional plastic bag. Once participants had made their selections for all four items, they were asked to bag their items using the bag they brought from home (not applicable if they chose not to take a bag from home in the first scenario), a single-use plastic bag, or a reusable bag that could be purchased for two dollars.

In the fourth scenario, participants returned to their apartment and were asked to sort out items for disposal according to a set of instructions on a flyer. The items presented were either recyclable plastic, recyclable plastic after cleaning, or non-recyclable—namely, a single-use plastic bottle (with water left), a plastic oil bottle (with a little oil left), a Styrofoam box (with food stains), bubble wrap, a potato chip bag (with crumbs), and a plastic sliced bread bag (with crumbs). For each item except the bubble wrap, participants could choose to wash items that they intended to recycle but were warned not to waste water for items intended for general waste. Afterward, participants could choose to dispose of each item in a commingled recycling bin or a general waste bin.

Each game playthrough took about 10 minutes. After participants completed the game, they were given a laptop to complete a post-test questionnaire online.

4.4. Measures

Prior knowledge about plastic waste was measured in the pre-test survey using five statements that were either scientifically true or false (e.g. 'Cardboard packaging has a lower negative environmental impact compared to single-use plastic packaging' [T]). Participants were asked to evaluate each statement with 'True', 'False', or 'I don't know.' We recoded each correct response as '1' and each wrong or 'I don't know' response as '0.' We then created a composite index by summing the scores for all five items with higher scores indicating higher levels of prior knowledge. Similar measures to assess prior knowledge were used in previous studies (Mustafa and Yusoff 2011; Parant et al. 2016).

The following variables were measured in the post-test survey. All were measured on a five-point Likert scale (1 = strongly disagree; 5 = strongly agree) except for the two attitude variables, which were measured on a five-point semantic differential scale.

Autonomy (Cronbach's $\alpha = .82$) was measured using the perceived choice subscale (seven items) from the Intrinsic Motivation Inventory (IMI; see Ryan, Mims, and Koestner 1983). We adapted the items to our context (e.g. 'I believe I had some choice about playing this game').

Autonomous motivation (Cronbach's $\alpha = .86$) was measured using 26 items adapted from the comprehensive relative autonomy index (C-RAI; Sheldon et al. 2017). The C-RAI consists of six subscales measuring intrinsic motivation, identified regulation, positive introjected regulation, negative introjected regulation, external regulation, and amotivation. Participants were asked why they played the VR game and to indicate their agreement with each of the 26 responses targeting the six types of motivation, ranging from the most autonomous (e.g. 'Because I enjoy the game') to the most controlled (e.g. 'I don't have good reasons for doing it'). We first created six composite indices for the six types of motivation separately, then obtained a relative autonomy index (RAI) using the formula RAI = 3*intrinsic motivation + 2*identified regulation + positive introjected regulation − negative introjected regulation − 2* external regulation − 3*amotivation (Sheldon et al. 2017). The weights were assigned based on the theorised position of each motivation type on the self-determination continuum (Ryan and Deci 2000).

Pro-environmental self-efficacy ($r = .72$) was measured using two items (e.g. 'I think that I am capable of reducing my personal plastic waste production') adapted from Reese and Junge (2017).

Environmental locus of control (Cronbach's $\alpha = .80$) was measured using nine items (e.g. 'My individual actions would improve the quality of the environment if I were to learn about the recycling facilities in my area') adapted from Ahn, Bailenson, and Park (2014).

We measured two attitude variables: attitude toward learning about plastic waste reduction (Cronbach's $\alpha = .79$) and attitude toward reducing plastic waste (Cronbach's $\alpha = .79$) using the same five sets of adjectives (e.g. 'bad – good'; Tonglet et al. 2004), with higher scores indicating more positive attitudes.

Behavioural intention (Cronbach's $\alpha = .92$) to mitigate the issue of plastic waste was measured using 15 items adapted from past research (Barr, Gilg, and Ford 2001). The items targeted participants' intention to reduce (e.g. 'In the next 12 months, I intend to avoid buying disposable products'), reuse (e.g. 'In the next 12 months, I intend to reuse jars and bottles wherever possible'), and recycle (e.g. 'In the next 12 months, I intend to sort out recyclable and non-recyclable trash and throw them into corresponding bins').

Lastly, to check if our manipulation was successful, we measured participants' sense of competition (Cronbach's $\alpha = .89$) using four items (e.g. 'I experienced a sense of competition in the VR game'), three of which were adapted from Hsu (2022).

5. Results

Results of the manipulation check indicated that participants in the competition condition ($M = 4.23$, $SD = .68$) experienced a significantly greater sense of competition ($t(59) = 4.46$, $p < .001$) compared to those in the non-competition condition ($M = 3.08$, $SD = 1.25$). There was no significant difference in participants' prior knowledge about plastic waste between the two conditions ($t(59) = 0.12$, $p = .90$).

Next, we converted the continuous variable prior knowledge ($M = 2.89$, $Mdn = 3.00$, $SD = 1.14$) into a categorical variable with three levels: high (above median, $N = 20$), medium (equal to median, $N = 17$), and low (below median, $N = 24$). After that, we conducted a series of two-way ANOVAs to examine the main effect of competition and the interaction effect between competition and prior knowledge on our dependent variables.

Given the potential for Type I errors due to multiple comparisons, we applied the Bonferroni correction to adjust the significance levels for our 14 pairwise tests for hypothesis testing. The original significance level of 0.05 was adjusted to 0.004 (0.05/14).

The main effect of competition on autonomy was non-significant ($F(1, 55) = 1.24$, $p = .27$). Hence, H1(a) was not supported. However, the interaction effect between competition and prior knowledge on autonomy was significant ($F(2, 55) = 9.54$, $p < .004$; see Figure 4a). Simple main effects analysis showed that participants in the competition condition (vs. non-competition) reported lower autonomy in playing the game when they had low ($M_{\text{Competition}} = 3.81$, $M_{\text{Non-competition}} = 4.48$, $F(1, 55) = 7.47$, $p = .008$) or high prior knowledge ($M_{\text{Competition}} = 3.92$, $M_{\text{Non-competition}} = 4.60$, $F(1, 55) = 6.26$, $p = .015$) about plastic waste. In contrast, participants in the competition condition (vs. non-competition) reported higher autonomy in playing the game when they had medium prior knowledge about plastic waste ($M_{\text{Competition}} = 4.60$, $M_{\text{Non-competition}} = 3.77$, $F(1, 55) = 8.05$, $p = .006$). Hence, H2 was partially supported.

Both the main effect of competition ($F(1, 55) = 1.92$, $p = .17$) and the interaction effect between competition and prior knowledge ($F(2, 55) = 2.66$, $p = .11$) on autonomous motivation were non-significant. Hence, H1(b) and H3 were not supported.

The main effect of competition on self-efficacy to curtail plastic waste was non-significant ($F(1, 55) = 0.88$, $p = .35$). Hence, H1(c) was not supported. However, the interaction effect between competition and prior knowledge on self-efficacy was significant ($F(2, 55) = 7.13$, $p < .004$; see Figure 4c). Simple main effects analysis showed that participants in the competition condition (vs. non-competition) reported lower self-efficacy when they had low prior knowledge about plastic waste ($M_{\text{Competition}} = 3.86$, $M_{\text{Non-competition}} = 4.69$, $F(1, 55) = 13.23$, $p < .001$). There was no significant difference in self-efficacy between the two conditions when participants had medium ($M_{\text{Competition}} = 4.67$, $M_{\text{Non-competition}} = 4.19$, $F(1, 55) = 3.15$, $p = .08$) or high prior knowledge ($F(1, 55) = 0.05$, $p = .83$) about plastic waste. Hence, H4(a) was supported.

The main effect of competition on environmental locus of control was non-significant ($F(1, 55) = 0.00$, $p = 1.00$). Hence, H1(d) was not supported. However, the interaction effect between competition and prior knowledge on environmental locus of control was significant ($F(2, 55) = 6.05$, $p = .004$; Figure 4d). Simple main effects analysis showed that participants in the competition condition (vs. non-competition) reported lower environmental locus of control when they had low prior knowledge about plastic waste ($M_{\text{Competition}} = 4.09$, $M_{\text{Non-competition}} = 4.66$, $F(1, 55) = 8.65$, $p = .005$). There was no significant difference in environmental locus of control between the two conditions when participants had medium ($M_{\text{Competition}} = 4.61$, $M_{\text{Non-competition}} = 4.21$, $F(1, 55) = 3.01$, $p = .09$) or high prior knowledge ($F(1, 55) = 0.65$, $p = .42$) about plastic waste. Hence, H4(b) was supported.

The main effect of competition on attitude toward learning about plastic waste reduction was non-

Figure 4. Interaction Effects Between Competition and Prior Knowledge.
Note: Y-axis is not drawn to scale.

significant ($F(1, 55) = 0.12$, $p = .73$). The interaction effect between competition and prior knowledge on this attitude variable was significant using the traditional significance level but not the corrected significance level ($F(2, 55) = 3.55$, $p = .035$; Figure 4e). Simple main effects analysis showed that participants in the competition condition (vs. non-competition) reported more positive attitudes toward learning when they had medium prior knowledge about plastic waste ($M_{\text{Competition}} = 5.00$, $M_{\text{Non-competition}} = 4.60$, $F(1, 55) = 4.59$, $p < .05$). There was no significant difference in attitude toward learning between the two conditions when participants had low ($F(1, 55) = 2.44$, $p = .12$) or high prior knowledge ($F(1, 55) = 0.08$, $p = .78$) about plastic waste. As for attitude toward reducing plastic waste, both the main effect of competition ($F(1, 55) = 0.01$, $p = .914$) and the interaction effect of competition and prior knowledge ($F(2, 55) = 1.77$, $p = .180$) were non-significant. Hence, H1(e) was not supported and H4(c) was not supported when the corrected significance level was used.

The main effect of competition on behavioural intention to mitigate the issue of plastic waste was non-significant ($F(1, 55) = 1.16$, $p = .29$). Hence, H1(f) was not supported. The interaction effect between competition and prior knowledge on behavioural intention was significant using the traditional significance level but not the corrected significance level ($F(2, 55) = 3.58$, $p = .035$; see Figure 4f). Simple main effects analysis showed that participants in the competition condition

Table 1. Summary of Hypothesis Testing Results

	Hypothesis	F	*p*	Results
H1a	Competition (vs. non-competition) has a negative effect on autonomy.	1.24	.271	Main effects (unsupported)
H1b	Competition (vs. non-competition) has a negative effect on autonomous motivation.	1.92	.172	Main effects (unsupported)
H1c	Competition (vs. non-competition) has a negative effect on pro-environmental self-efficacy.	0.88	.353	Main effects (unsupported)
H1d	Competition (vs. non-competition) has a negative effect on environmental locus of control.	0.00	1.000	Main effects (unsupported)
H1e	Competition (vs. non-competition) has a negative effect on attitude toward learning about plastic waste reduction	0.12	.726	Main effects (unsupported)
	Competition (vs. non-competition) has a negative effect on attitude toward reducing plastic waste.	0.01	.914	Main effects (unsupported)
H1f	Competition (vs. non-competition) has a negative effect on behavioural intention.	1.16	.286	Main effects (unsupported)
H2	Prior knowledge moderates the effect of competition (vs. non-competition) on autonomy.	9.54	.000	Interaction effects (supported)
H3	Prior knowledge moderates the effect of competition (vs. non-competition) on autonomous motivation.	2.66	.108	Interaction effects (unsupported)
H4a	Prior knowledge moderates the effects of competition (vs. non-competition) on pro-environmental self-efficacy.	7.13	.002	Interaction effects (supported)
H4b	Prior knowledge moderates the effects of competition (vs. non-competition) on environmental locus of control.	6.05	.004	Interaction effects (supported)
H4c	Prior knowledge moderates the effects of competition (vs. non-competition) on attitude toward learning about plastic waste reduction	3.55	.035	Interaction effects (supported)
	Prior knowledge moderates the effects of competition (vs. non-competition) on attitude toward reducing plastic waste.	1.77	.180	Interaction effects (unsupported)
H4d	Prior knowledge moderates the effects of competition (vs. non-competition) on behavioural intention.	3.58	.035	Interaction effects (supported)

(vs. non-competition) reported lower behavioural intention when they had low prior knowledge about plastic waste ($M_{\text{Competition}} = 3.85$, $M_{\text{Non-competition}} = 4.53$, $F(1, 55) = 8.85$, $p = .004$). There was no significant difference in behavioural intention between the two conditions when participants had medium ($F(1, 55) = 0.25$, $p = .62$) or high prior knowledge ($F(1, 55) = 0.09$, $p = .76$) about plastic waste. Hence, H4(d) was marginally supported. A summary of the hypothesis testing results is presented in Table 1. Means and standard errors of the simple main effects analysis are shown in Table 2 while graphs depicting the interaction effects between competition and prior knowledge are presented in Figure 4.

6. Discussion

The use of competition in serious games remains widely contested due to competing theories and empirical evidence on its impacts on a game's efficacy. The present study was guided by two research goals. First, we sought to understand the inconsistent effects of competition on motivation and A-PEB in serious games. Moreover, we investigated if the effects of competition could be moderated by a third variable—prior knowledge about the game topic. Guided by SDT, this research is among the first to empirically test the interaction effects between competition and prior knowledge on motivation and A-PEB. Second, we looked toward evaluating the efficacy of a competitive VR serious game with a pro-environmental narrative.

The results of this study contrasted with both SDT's hypothesis that competition would have a negative impact on a serious game's efficacy (Deci, Koestner, and Ryan 1999) as well as a body of empirical research that suggested competition's positive impact on various motivations or A-PEB (e.g. Cagiltay, Ozcelik, and

Table 2. Adjusted Mean (SE) Scores for Competition x Prior Knowledge Analysis of variance on dependent variables.

	Competition			Non-competition			
Prior Knowledge	Low	Medium	High	Low	Medium	High	*F (p)*
Autonomy	3.81 (.18)	4.60 (.20)	3.92 (.18)	4.48 (.17)	3.77 (.21)	4.60 (.20)	**$F(2, 55) = 9.54$, $p < .004$**
Autonomous motivation	9.46 (2.11)	14.33 (2.33)	12.05 (2.11)	15.02 (1.94)	10.09 (2.47)	14.86 (2.33)	$F(2, 55) = 2.66$, $p = .11$
Pro-environmental self-efficacy	3.86 (.17)	4.67 (.19)	4.50 (.17)	4.69 (.15)	4.19 (.20)	4.56 (.19)	**$F(2, 55) = 7.13$, $p < .004$**
Environmental locus of control	4.09 (.14)	4.61 (.16)	4.57 (.14)	4.66 (.13)	4.21 (.17)	4.40 (.16)	**$F(2, 55) = 6.05$, $p = .004$**
Attitude toward learning about plastic waste	4.60 (.12)	5.00 (.13)	4.82 (.12)	4.85 (.11)	4.60 (.14)	4.87 (.13)	**$F(2, 55) = 3.55$, $p = .035$**
Attitude toward reducing plastic waste	4.49 (.12)	4.98 (.13)	4.84 (.12)	4.66 (.11)	4.70 (.14)	4.91 (.13)	$F(2, 55) = 1.77$, $p = .180$
Behavioural intention	3.85 (.17)	4.38 (.19)	4.42 (.17)	4.53 (.16)	4.24 (.20)	4.35 (.19)	**$F(2, 55) = 3.58$, $p = .035$**

Note. Values are Mean (SE).

Ozcelik 2015; Cheng et al. 2009; Ho, Hung, and Kwan 2022; Plass et al. 2013; Zhou, Lin, and Mou 2023). Rather, we identified that competition had differential impacts based on a player's prior knowledge (low vs. medium vs. high) about the game topic. The results demonstrated that competition had the greatest negative impact on motivation and A-PEB when players had low prior knowledge about plastic waste. Comparatively, competition had a positive impact on motivation and A-PEB among players who had medium prior knowledge about plastic waste. This study provides a partial explanation for the inconsistent impacts of competition in serious games and demonstrates a need for more research on the moderating influence of prior knowledge on various outcomes.

In addition, these findings are congruent with Deterding's (2011) concept of situated motivational affordances. In our context, motivational affordances first refer to the properties, or features, of a serious game that facilitate the fulfilment of the players' psychological needs, such as autonomy (Zhang 2008). However, the capacity of these features to induce experiences of players' psychological needs is often situational and thus dependent on factors external to the serious game. This includes the environment within which the serious game is played (e.g. in private or with an audience), the presence of external incentives, and the ability or disposition of each individual player (i.e. their prior knowledge; Deterding 2011). While past research has investigated the moderating influence of external factors like trait competitiveness (Amo et al. 2020) on the relationship between game features and individuals' motivation, this study is among the first to suggest the moderating influence of prior knowledge on the effects of competition, operationalised as a leaderboard.

6.1. Moderating influence of prior knowledge on effects of competition on motivation and A-PEB

First, the results suggest that when players possess a certain level of prior knowledge, they might be less susceptible to the negative impacts of competition on motivational outcomes. Individuals who exhibited lower levels of prior knowledge experienced lower levels of autonomy while those with medium levels of prior knowledge reported higher levels of autonomy. Taking the view that competition diminishes autonomy by limiting the control one has over the game environment and their in-game decisions, the results align with past research that an individual's competency in the subject area to be learned can protect against competition's thwarting effect on their autonomy (Radel, Pelletier, and Sarrazin 2013). In contrast, when individuals perceived themselves to be less competent, they relinquished their need for autonomy and accepted the controlling nature of the game environment. The results indicate that players with different levels of prior knowledge respond differently to competitive environments, especially in terms of autonomy and motivation. This suggests that adaptive or personalised learning environments could enhance the effectiveness of serious games or educational interventions. For example, players with lower prior knowledge may benefit from a less competitive, more supportive game environment to foster autonomy, while those with medium prior knowledge could thrive in more competitive settings.

Second, competition, while suggested to improve players' attention to and engagement in a serious game to encourage A-PEB (Cheng et al. 2009), may conversely add undue amounts of cognitive load, processing, and complication to a game. For example, competition may also risk distracting players from learning objectives by encouraging focus on extrinsic rewards like point-scoring or increasing their stress levels (Licorish et al. 2018). Among players with lower levels of prior knowledge, participants in the competition condition (vs. non-competition) reported lower levels of pro-environmental self-efficacy, environmental locus of control, and behavioural intention to mitigate the issue of plastic waste. Low levels of prior knowledge may thus be detrimental for players by increasing the effort they need to process information in the game. Past research instead suggests that when players are familiar with the concepts introduced through the game, they experience a reduced burden of decision-making as they can engage in more efficient and automatic information processing (Barnidge et al. 2022). This subsequently allows players with adequate prior knowledge to concentrate on learning within the serious game. For instance, players with medium levels of prior knowledge participants in the competition condition (vs. non-competition) exhibited more positive attitudes toward learning.

However, we also found that competition (vs. non-competition) did not have a significant impact on several A-PEB among players with medium and high prior knowledge. Furthermore, players with high prior knowledge exhibited lower levels of autonomy in the competition condition. This result may be attributed to the simplicity of the game developed for this experiment; past literature suggests that learning aids that benefit people with low prior knowledge may not support the learning of those with high prior knowledge. Rather, the use of inappropriate learning aids could hinder the improvement of motivation and A-PEB; a game that necessitates medium- or high-knowledge players to process redundant information may conversely have a disruptive effect on their cognition as they attempt to find congruity with their prior knowledge and the new information (Kalyuga and Renkl 2009). By burdening their processing with the additional cognitive load of verifying their prior knowledge, individuals may thus experience a decreased sense of autonomy or control over their in-game decisions or the game's objectives.

7. Implications, limitations, and future research

The study acknowledges the substantial body of research on online games that has successfully applied Self-Determination Theory (SDT) to understand player motivation, engagement, and learning. This literature provides valuable insights into how the satisfaction or frustration of psychological needs (autonomy, competence, and relatedness) can drive various outcomes, from enhanced motivation to problematic behaviours such as gaming addiction or cheating (Lee, Chang, and Li 2024; Brühlmann et al. 2020).

However, while many findings from online games are indeed applicable, this study extends the SDT framework into the domain of serious games, specifically in a virtual reality (VR) setting focused on promoting pro-environmental behaviours. The unique contributions of this study lie in its examination of how competition, a commonly used game element, interacts with players' prior knowledge to influence motivation and behavioural outcomes in a solitary VR serious game—an aspect that has not been extensively explored in the existing online game literature.

The current study introduces prior knowledge as a moderator in the relationship between competition and motivation. Prior knowledge is analogous to perceived competence, which has been shown to play a critical role in online games. For example, in Qian et al. (2022), relatedness was found to be the most significant predictor of esports fan engagement. This study extends those findings by demonstrating that competition's impact on autonomy and competence varies significantly based on players' prior knowledge levels. Thus, while relatedness is critical in multiplayer online games, the findings of this study suggest that prior knowledge is a more crucial factor in solitary serious game settings, particularly when examining the effects of competition.

The role of competition in fostering learning and behavioural change has been widely studied in online games. Brühlmann (2020) identified four distinct motivational profiles among League of Legends players, showing that players with high intrinsic motivation and satisfaction of competence were more likely to respond positively to competition. Similarly, Lee, Chang, and Li (2024) found that intrinsic motivation in competitive online games negatively influenced cheating behaviour. However, these studies did not explore how competition interacts with individual characteristics such as prior knowledge. This study fills that gap by showing that players with medium levels of prior knowledge are more likely to experience a positive impact on pro-environmental behavioural intentions in response to competition, while those with low prior knowledge might experience competition as a threat to their competence, thereby reducing their motivation.

While many studies on online games using SDT have focused on general learning outcomes or entertainment behaviours, such as engagement and skill mastery (Hong, Wilkinson, and Rocha 2023), this study explores a distinct behavioural domain—pro-environmental behaviours—within a serious game context. This novel application of SDT highlights how competition, when aligned with players' knowledge levels, can promote specific behavioural intentions beyond traditional gaming contexts. By doing so, the study contributes to the ongoing discourse on how game design elements can be strategically used to promote socially and environmentally beneficial behaviours.

Previous research, such as that by T'ng, Ho, and Pau (2023), has shown that competition can lead to negative outcomes such as Internet Gaming Disorder. The current study builds on these findings by demonstrating that competition can also negatively impact motivation and pro-environmental behaviours when players' prior knowledge is low, leading to a lack of competence satisfaction. This underscores the importance of aligning game elements with player characteristics to prevent need frustration and ensure positive behavioural outcomes.

Unlike the majority of online game research, which emphasises the role of relatedness in multiplayer settings, this study justifies the exclusion of relatedness in its research model due to the solitary nature of the VR serious game. Findings from Reer and Krämer (2020) and Qian et al. (2022) demonstrated that relatedness significantly contributes to motivation and engagement in multiplayer contexts. However, in a solitary VR setting, autonomy and competence are more critical drivers of motivation, making prior knowledge a more appropriate focus in this study.

This study reflected upon the dynamic role that competition has played in SDT literature and serious games research and has several implications for future research. These findings suggest that the effects of competition on the motivations and antecedents to pro-environmental behaviour are conditional upon individuals' personal traits (i.e. prior knowledge). This should be considered not only for scholars seeking to assess the effects of competition in digital environments but also for practitioners seeking to incorporate elements of competition into their pedagogy.

A key contribution of the present study is in providing some clarity to the contradictory views in extant literature regarding the use of competition in learning environments. From a SDT perspective, it might be worth refraining from introducing competitive elements in serious game settings due to its dampening effect on learners' autonomous motivation, which is closely linked to A-PEB (Kam and Umar 2023). By examining prior knowledge as a moderator in this relationship, our results suggest that the right question to ask is not whether competition is good or bad for learning, but when competition is good or bad for learning. Specifically, we found significant interaction effects between competition and prior knowledge on motivational outcomes and A-PEB. The pattern of interaction suggests that competition is detrimental to learning for individuals with low prior knowledge about the subject to be learned, while competition can produce positive effects on some motivational outcomes and A-PEB for individuals with medium prior knowledge. This helps to reconcile the mixed findings regarding the effects of competition in past studies.

Our results corroborate the claim made by Chen and colleagues (2019; Chen, Shih, and Law 2020b) that the effects of competition may be moderated by other variables. While their meta-analysis (Chen, Shih, and Law 2020b) found that some factors external to the learners (e.g. game type and content to be learned) moderated the effects of competition in serious games, research on how individual characteristics influence the effects of competition in learning environments remains scarce. As one of the few studies that have investigated this topic and the first study to examine how prior knowledge moderates the effect of competition in a VR serious game, this study represents a valuable addition to the extant literature.

In addition to this study, other scholars have also suggested the moderating effects of competitiveness as a personality trait (Song et al. 2013) and the player's gender (Deci et al. 1981). Given the vast amount of potential variability in research on serious games, competitive environments, and environmental education, future studies can look toward understanding the moderating influence of other dispositional traits, such as players' competitive trait anxiety—the tendency to experience stress in competitive environments (Petrie 1993).

Theoretically, our results suggest that theories used in education should consider how the interplay between the learning environment and learner characteristics affects the desired A-PEB. Researchers may also consider the potential for conflict among various game elements in their production of both autonomous and controlled motivation. This present study posited that a competitive serious game could dampen players' experience of autonomy among those with low levels of prior knowledge. Hence, future research could investigate the conditions within which varying game elements could evoke greater autonomy to promote more effective learning in serious games. Studies should also include a measure of controlled motivation to test the potentially biasing effects that certain game elements could have on players' overall motivation.

The findings of this study contribute to a deeper understanding of SDTin the context of game-based learning and serious games by demonstrating that the interaction between competition and prior knowledge significantly influences the satisfaction of psychological needs and subsequent behavioural outcomes. The integration of SDT with the concept of prior knowledge as a moderator adds a novel dimension to how we conceptualise the role of competition in gaming environments. This study expands on existing research by providing empirical evidence for the nuanced effects of competition on motivation and behaviour, which vary depending on individual differences such as the player's prior knowledge.

Our results also contribute to a young body of work done at the intersection of competition, serious games, environmental education, and immersive environments. However, we acknowledge that these findings may not be applicable when the medium, and thus complexity, of serious games change. For example, past research has already identified VR-based environmental education to have greater effects on various A-PEB compared to traditional modes of delivery such as through written text or video (e.g. Kleinlogel et al. 2023). Hence, scholars should continue to investigate not only the influence of different game elements on motivational outcomes, A-PEB, and other learning outcomes but also the impact of newer mediums of communication and game foci.

Practically, our results highlight the importance of evaluating learners' competence level with respect to the learning task before determining whether competition should be introduced in the educational process. Findings from the present study indicate a need for serious game developers, focusing on environmental education or other educational contexts, to segment their audiences based on qualities like prior knowledge about the game topic.

The findings of this study provide valuable guidance for serious game providers on designing effective learning experiences that align with players' motivational needs. To enhance the impact of serious games, providers should focus on adaptive game design that considers players' prior knowledge when implementing competitive elements. For example, dynamic difficulty adjustment systems can be used to tailor competition levels, ensuring that experienced players are challenged without causing frustration for less knowledgeable participants. This strategy helps to satisfy the competence need by providing an optimal challenge for each individual, thereby enhancing motivation and engagement.

Additionally, incorporating personalised feedback and allowing players to set their own goals can maintain players' sense of autonomy, even within a competitive environment. Providers should offer options that enable players to select their preferred competitive intensity or learning paths. This autonomy-supportive approach ensures that competition is perceived as a self-directed challenge rather than an external pressure, which can enhance intrinsic motivation.

By implementing these strategies, providers of serious games can create more personalised and effective learning experiences that not only enhance player motivation but also promote positive behavioural outcomes, such as increased engagement in pro-environmental behaviours. These implications are directly grounded in the study's findings and offer actionable recommendations for improving the design and effectiveness of serious games.

Despite its contributions, this study holds a set of limitations that future research can seek to address. First, we offered our study participants one mode of gameplay that only differed between its inclusion of competitive game elements. As we identified that players with high levels of prior knowledge might benefit from a game that is developed to complement their capabilities, future research can look toward empirically testing the effects of a serious game across varying levels of difficulty. Scholars may also investigate how game difficulty might interact with players' prior knowledge to influence motivational outcomes, A-PEB, and other learning outcomes.

Second, a game's genre or gameplay style can interact with players' prior knowledge and experience of competition in different ways. For example, open-world games that encourage exploration may encourage motivation and learning among players with high levels of prior knowledge by supporting their autonomy and need for cognition (Hilgard, Engelhardt, and Bartholow 2013). In contrast, games that feature simple decision-making paths and guidance may be more appropriate for lessening the cognitive load among players with low prior knowledge.

Third, this study included only undergraduates as participants and was conducted in a controlled laboratory setting. Prior studies have shown that the effects of competition in game contexts may vary among different demographics, such as between children and adolescents (Lwin et al. 2016). Additionally, experiments in strictly controlled laboratory settings may yield different effects compared to observational experiments (e.g. Sun and May 2013). Therefore, future research could empirically assess the effects of competition in serious games across various demographic groups using a field experiment approach.

Fourth, in line with prior research, this study only relied on one operationalisation of competition as an in-game leaderboard (e.g. Amo et al. 2020; Chen, Law, and Huang 2019; Park and Kim 2021). However, other game and real-world elements may also contribute to creating a competitive game element; for example, some studies have induced a sense of competition by having participants play against a confederate (Roy and Ferguson 2016). It would thus be worthwhile to explore how varying degrees and types of competition manipulation would interact with players' prior knowledge to influence motivational outcomes, A-PEB, and other learning outcomes.

Fifth, we acknowledge that the elements of competition employed in the experiment may not always be present outside the game to incentivize pro-environmental behaviours, especially in actual-world pro-environmental campaigns. Therefore, the findings from our study may not be broadly applicable to pro-environmental campaigns but offer specified insights for practitioners looking to utilise serious games with pro-environmental narratives. Moreover, scholars can consider conducting longitudinal research to assess if both competitive and non-competitive serious games can promote sustained pro-environmental behaviours over time.

Sixth, Singapore is often considered a society with a strong competitive culture, largely driven by its emphasis on meritocracy, economic success, and global competitiveness (Bellows 2009; Tan 2019). Consequently, the effectiveness of competition-based interventions may differ in societies with a weaker competitive culture, potentially affecting the generalizability of our findings. Future studies could explore this by comparing how societies with differing cultural priorities, particularly those that de-emphasise competition, might yield varying results.

Lastly, while the sample size of our study is sufficient to detect medium-to-large effect sizes, as is typical in social and behavioural research (Cohen 1992), we recognise that a larger sample would offer increased statistical power and allow for the detection of smaller effect sizes. As a result, future research could benefit from expanding the sample size to increase the robustness and generalizability of the findings and provide greater precision in estimating smaller effects. Despite this, we believe that the quality of our experimental design and the controlled environment in which the study was conducted mitigates some of these concerns, ensuring that the data collected is both reliable and meaningful within the context of the study.

8. Conclusion

Guided by self-determination theory, this study examined the effect of competition on motivations for and antecedents to pro-environmental behaviour (A-PEB) in a virtual reality serious game about plastic waste. It highlighted the importance of considering the moderating influence of prior knowledge when assessing the effects of competition in digital learning environments. The findings provide insights into the dynamic effects of competition, suggesting that its influence on learning is neither inherently positive nor negative, but depends on situated motivational affordances—including individual differences like the players' prior knowledge. Findings indicate that competition may hinder motivation and A-PEB for individuals with low prior knowledge, while potentially benefiting those with medium prior knowledge. Future research should consider how other variations in the learning environment and among learner characteristics might influence the effects of competition when it comes to motivation and other relevant learning outcomes.

Notes

1. Since the conception of the model of responsible environmental behaviour, scholars have developed and successfully validated the concept of *environmental locus of control* (Cleveland, Kalamas, and Laroche 2005), which is now frequently used in place of the more generalised locus of control measure to predict pro-environmental behaviour (e.g., Ahn, Bailenson, and Park 2014). As environmental locus of control relates to individuals' 'sense of responsibility for and ability to affect environmental outcomes', this variable also replaced the personal responsibility measure.

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