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Balancing learning and enjoyment in serious games: Kerbal Space Program and the communication mediation model

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ABSTRACT

When designed well, serious games can support effective learning. This study used the communication mediation model to examine the process and outcomes of playing serious games, in this case, the science-themed game, *Kerbal Space Program*. During a 4-h research session, 241 undergraduate students played through the game's tutorial missions and completed surveys to measure variables of interest. Results of structural equation modeling showed that game progress was positively related to self-efficacy in computer gaming ($\beta = 0.26$) and ordinary science intelligence ($\beta = 0.13$). Knowledge acquisition was positively related to game progress ($\beta = 0.21$) and positively predicted experiential attitude ($\beta = 0.35$) and instrumental attitude ($\beta = 0.35$) toward the game. Finally, gaming continuance intention was positively related to experiential attitude ($\beta = 0.68$). In addition to those direct effects, there were several indirect effects consistent with the communication mediation model. These findings echo past scholarship on balancing the serious side and the gaming side of serious games but emphasize player traits and other psychological factors of the gaming experience.

Although computer games are typically designed for entertainment purposes, many have additional pedagogical aspects. Researchers have labeled these kinds of games as *serious games* because they can serve more serious purposes, such as training and education (Laamarti et al., 2014). Serious games can be effective instructional tools because they create virtual spaces for individuals to experiment and receive feedback (Pivec & Kearney, 2007; Tobias & Fletcher, 2007) and safely learn from their failures (Toh & Kirschner, 2020). These affordances of serious games are especially useful for science education, enhancing not only scientific knowledge but also interest in science and identity as someone who knows science (Honey & Hilton, 2011).

There is a growing body of research about serious games in education. Many of these studies focus on game design elements that can facilitate learning different topics (De Jans et al., 2017; Mildner & Mueller, 2016; Wendel et al., 2013). Several studies focus on learning as knowledge acquisition (Feng et al., 2018), often as an element of coursework in structured learning settings (Lamb et al., 2018). Other studies have examined collaborative learning and knowledge co-creation related to playing serious games (Sánchez and Olivares, 2011) and the value of serious games in informal learning environments, such as museums (Wang & Nunes, 2019). But we are not aware of many studies about more self-directed learning from serious games, where players can engage with the game at their own pace and without assigned learning objectives. What kinds of individuals are inclined to engage with serious games in this way, learn from them, and further orient themselves toward such learning? These are present research gaps (Jacobs, 2021).

We study this subject using the communication mediation model (McLeod et al., 2002), which some prior research has used to

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understand the effects of computer games on players (Jung, 2020). According to that model, individuals have a pre-reception orientation toward or away from engaging with a media stimulus. After engaging with a stimulus, they may reason about it and form a post-reception orientation that may motivate them to engage more with the same kind of stimuli. To study this process, we present a case study of *Kerbal Space Program*, a computer game in which players construct and launch space vehicles to explore a fictional planetary system. In this context, an application of the communication mediation model may include an orientation to computer games and science, playing and learning from the game, forming attitudes about the experience as being enjoyable and educational, and desiring to play more of the game in the future. In the following sections, we review the literature on game-based learning and develop hypotheses around the communication mediation model to understand the learning process and outcomes of playing serious games.

1. Literature review

1.1. Game-based learning

Contrary to stereotypical implications of video games having harmful effects on players, a large body of research suggests they can be useful tools for teaching and learning (Granic et al., 2014). Video games excel as teaching tools because they can capture and hold the attention of players through entertaining mechanics such as animations, narrative, and interactivity (Dyck et al., 2003; Ritterfeld & Weber, 2006), while utilizing effective learning principles to guide players as they progress through game content (Gee, 2006, 2009). Further, well-designed video games can facilitate the so-called "zone of proximal development" (see Eun, 2019) by increasing the difficulty gradually as players develop the level of skill necessary to meet the challenge (Bork, 2012; Verma et al., 2019). The skills developed through video games often have real-world benefits, such as enhanced problem solving (Adachi & Willoughby, 2013), spatial-rotation abilities (Martin-Gutiérrez et al., 2009; Spence & Feng, 2010), and even surgical ability (Lynch et al., 2010; Ou et al., 2013). These might be considered indirect benefits of gaming, but studies also find more direct benefits when games are used in structured educational environments. For example, teachers have used games like *Civilization* and *The Sims* in conjunction with traditional classroom activities to effectively teach students about history and societal development (McCall, 2016; Squire & Jenkins, 2003; Young et al., 2006). Such games offer educational experiences to all players, even those playing purely for entertainment, but they work best as teaching tools within a structured learning environment that guides players toward specific goals.

In contrast to entertainment-oriented games with education-related benefits, some games are designed to support learning even outside of a structured learning environment by incorporating educational content within the gameplay. Scholars use the oxymoron, "serious games," to label these kinds of games, which may facilitate learning more effectively than games focused mostly on entertainment (Laamarti et al., 2014; Ritterfeld et al., 2009). Serious games are used in many different venues, most traditionally in academic education, but also in occupational or military training, health behavior motivation, persuasion of social or political attitudes, and product marketing (Ritterfeld et al., 2009). Despite decades of serious game development and research on serious games, there is still no cohesive understanding of when serious games are more effective than alternative approaches to teaching, motivating, and persuading (Jacobs, 2020). That said, serious games are more likely to be successful when they balance the serious and the playful nature of the game by embedding the educational goal into the gameplay itself, building the content on a strong foundation of domain expertise, utilizing appropriate interaction technologies, and offering intuitive game mechanics that naturally support the game's serious intent without adverse effects (Caserman et al., 2020). Achieving this serious-game balance is a challenge that many, if not most, game developers have yet to conquer. This is why serious games are often referred to as "chocolate-covered broccoli," representing meager attempts to hide the serious nature of the instrument behind an uncomplimentary and inauthentic façade of playfulness (Hopkins & Roberts, 2015; Jacobs, 2021). Still, some games do achieve an appropriate serious-game balance, enticing people to play because they choose to, not because they are forced to. This can facilitate enjoyment in learning.

1.2. Communication mediation

Learning is a process of integrating new information into existing knowledge structures. Mayer (2019) presented a cognitive model of multimedia learning, which describes learning from multimedia sources, such as computer games. According to that model, individuals use their senses to perceive words and images appearing in a stimulus. They attend to some pieces of information, which are transferred to working memory. To process novel information, individuals draw on their long-term memory, construct new knowledge, and fit that knowledge back into their long-term memory. The more actively individuals process that information, the deeper their learning. However, Mayer (2019) argued that a model of active processing and deep learning also needs to account for learning motivations and metacognition. The role of motivation is especially relevant to the current study, which we situate within the communication mediation model (Cho et al., 2009; McLeod et al., 2002). Like the cognitive model of multimedia learning, this model is interested in cognitions about and outcomes of informational stimuli. Scholars have considered the effects of computer games from the perspective of media psychology (Ennemoser, 2009; Lee & Peng, 2006), so the communication mediation model is an apt framework for the current research.

Cho et al. (2009) developed the communication mediation model to counter arguments that mass media are harmful to political participation. In contrast with that prior view, they argued that exposure to political campaign messages can lead to greater political knowledge and interest because it encourages reflection and discussion. The model specifies a causal chain of five variables explaining media use and outcomes. These variables include a pre-reception orientation (O_1), stimulus (S), reasoning (R_1), post-reception orientation (O_2), and response (R_2). This framework often takes an abbreviated form as the O–S-R-O-R model (Cho et al., 2009), which drew on earlier work around political communication (Shah et al., 2007) and more generally the stimulus-response framework (Markus & Zajonc, 1985). The idea of this framework is that individuals are inclined toward certain communication stimuli and tend to engage with those stimuli. Based on their reasoning about novel information, they form new inclinations that affect their subsequent engagement with the same kinds of stimuli or topics.

Although most of the research on the communication mediation model focuses on political communication, scholars have applied it to other domains, such as entertainment media and health communication (Lee, 2017). We use it in the context of science-themed serious games, which is in the domain of science communication. This is not to say that science communication is unrelated to political participation, as an important aspect of scientific literacy is understanding the role of science in society and policymaking (Jarman & McClune, 2007). But the current work focuses not on that aspect of scientific literacy. Rather, it emphasizes the development of scientific knowledge and interest, and the communication mediation model seems a fitting framework to understand that process. In the sections below, we define each element of the model with respect to science-themed serious games.

1.3. Pre-reception orientation

The first variable in the communication mediation model is the pre-reception orientation, which is a motivational or cognitive state that influences how much individuals use certain media and process media stimuli (McLeod et al., 2002). In the context of computer games, different psychological factors affect what kinds of games are interesting to individual players (Mildner & Mueller, 2016). For instance, sequential learners prefer puzzle games, while more intuitive learners prefer casual games (Khenissi et al., 2016). To explain preference for science-themed serious games, there are several relevant concepts of which the current study focuses on two: self-efficacy in computer gaming (Ketelhut, 2011) and ordinary science intelligence (Kahan, 2017). We selected them because they are specifically relevant to science-themed serious games: one emphasizes skills related to playing computer games and the other is related to the understanding of scientific ideas. Individuals with high levels of both ought to be especially oriented toward science-themed serious games.

These two concepts have straightforward meanings. First, self-efficacy in computer gaming reflects a perceived ability to succeed at playing computer games. Those perceptions may be related to beliefs about behavioral ability and about the outcomes of performing the behavior, both of which underlie self-efficacy in general (Bandura, 1977). Thus, individuals with a high degree of self-efficacy in computer gaming will regard themselves as capable players and tend to predict positive outcomes of their gaming efforts. Second, ordinary science intelligence reflects the ability to recognize, interpret, and make decisions about scientific information (Kahan, 2017). The concept has several dimensions, including knowledge about basic scientific facts and the scientific method, quantitative reasoning, and cognitive reflection. That last dimension refers to the ability to solve problems through critical examination while resisting intuitive but unsound solutions (Frederick, 2005).

1.4. Stimulus

The pre-reception orientation can affect how much individuals approach or avoid a stimulus. Although “stimulus” refers broadly to a feature of an environment or a situation that may trigger a response in an individual (Kantor, 1933), the communication mediation model mainly regards a stimulus in terms of the amount of exposure to a message. This conceptualization traces back to early research on the effects of political propaganda (Lasswell, 1927). The channel of communication conveying a stimulus can include both the media and interpersonal conversation (Cho et al., 2009; Jung, 2020). From a subtly different view, the concept of stimulus can also reflect the amount of engagement with or attention to a message, where incidental exposure can trigger more active information seeking, and such seeking indicates stimulus engagement (Yamamoto & Morey, 2019). In the context of a science-themed computer game, merely trying the game might not constitute a strong enough stimulus to trigger a response. Rather, how far a player progresses through the game provides a straightforward indication of stimulus engagement (Xiao et al., 2018). As a starting point in the communication mediation process, we propose a linkage between pre-reception orientation and stimulus engagement. This prediction is a conceptual replication of prior work.

H1. Game progress is positively related to (a) self-efficacy in computer gaming and (b) ordinary science intelligence.

1.5. Reasoning

When individuals engage with a media message, they may reason about it by elaborating or reflecting on its content. In addition to such intrapersonal processes, Cho et al. (2009) argued that collective consideration, such as interpersonal discussions about a topic, also involves reasoning. They further clarified that reasoning is not necessarily rational but may include illogical or emotional responses based on personal or group beliefs. Although the original empirical test of this concept focused on interpersonal processes, its conceptualization drew partly on Eveland (2001), who hypothesized that political knowledge is an outcome of news attention and elaborative processing. The operationalization of elaboration focused on individuals’ subsequent reflection about and interpretation of new stories. In the same vein, Lee et al. (2019) studied reasoning about cancer information as reflective integration.

In slight contrast with those prior studies, the current study operationalizes elaboration in terms of knowledge acquisition. Generally, scholars treat knowledge acquisition as a post-reception orientation rather than a reasoning variable (Cho et al., 2009; Jung et al., 2011; Yamamoto & Morey, 2019). We agree with that conceptualization because knowledge acquisition indicates the presence of cognitive structures that did not exist prior to stimulus exposure. However, to gain knowledge from a stimulus, individuals need to actively attend to it (Lang, 2000), and meaningful learning involves abstraction and elaboration about information (Eysink & de Jong, 2012). Namkoong et al. (2017) argued similarly that media use, in general, may be a reasoning variable because it is an outcome of mental elaboration about specific content. Consistent with that perspective, we are not conceptualizing knowledge acquisition as elaboration, per se, but as an indication of it. Knowledge acquisition occurs when individuals are exposed to and cognitively process novel information in a learning environment. The more information individuals encounter, the more information about which they can reason and learn. This leads to a straightforward hypothesis:

H2. Knowledge acquisition is positively related to game progress.

1.6. Post-reception orientation

The post-reception orientation is a subsequent motivational or cognitive state related to exposure to and reflection about the message. As noted earlier, scholars often study this as knowledge acquisition, but other conceptualizations are more attitudinal, including things like environmental beliefs (Lu, 2021) and attitude toward smoking (Namkoong et al., 2017). In the case of a science-themed serious game, a relevant post-reception orientation would reflect the experiential and instrumental attitudes players form about it. Experiential attitudes are related to feelings of entertainment and leisure, while instrumental attitudes pertain to more functional attributes of media content, such as informativeness. To that point, Moizer et al. (2019) conceptualized user experience of serious games in terms of having an immersive and positive gaming experience and regarding the game as a good tool for receiving feedback and learning. Although the concepts also had conative dimensions, such as feelings of competence, their operationalizations were largely attitudinal. Drawing on the communication mediation model, Rosenthal (2018) studied experiential and instrumental uses of YouTube to learn about science. He argued that such uses reflect how individuals orient themselves to content that can be both informational and entertaining. In related work, Steiner et al. (2015) presented a conceptual framework for the pedagogical value of serious games. They argued that the learning process involves gamer perceptions about satisfaction and usability, which align respectively with experiential and instrumental attitudes.

We expect that experiential attitude is related to self-efficacy in gaming because skilled players have an easier time succeeding at games (Darvishi et al., 2020). And we expect that instrumental attitude is related to ordinary science intelligence because having prior domain knowledge is related to subsequent learning within that domain (Sun et al., 2018). Furthermore, we suggest knowledge acquisition, as an indication of reasoning, may be related to both kinds of attitudes. The linkage with instrumental attitude is intuitive: individuals who learn more from the game ought to regard it as more informative. The linkage with experiential attitude is less intuitive but easy enough to argue. If success in a serious game requires that players understand the informational content, then those who have difficulty grasping the content will tend to struggle with succeeding in the game. This is not to say failure cannot be fun, but it tends to be fun only when it leads to learning and subsequent improvement (Whitton & Langan, 2019). So those who learn more from a game also ought to regard it as more enjoyable.

H3. (a) Experiential attitude toward the game is positively related to self-efficacy in computer gaming and (b) instrumental attitude toward the game is positively related to ordinary science intelligence.

H4. Knowledge acquisition is positively related to (a) experiential attitude and (b) instrumental attitude toward the game.

1.7. Response

After forming a new orientation to a topic, individuals may be motivated to engage in a new behavior. The original work on the communication mediation model examined political participation as a behavioral response to political communication. There, the stimulus was engagement in online political communication, which is a type of political participation (Cho et al., 2009). Similarly, Jung (2020) conceptualized response in terms of behaviors such as writing and reading comments about online political games. But behavioral responses are not limited to the arena of political communication. Lu (2021) used the communication mediation model to study green purchasing behavior and environmental citizenship as behavioral outcomes of media use. From a health communication perspective, Namkoong et al. (2017) studied smoking intention as a response to an antismoking communication intervention. Notably, they found that smoking intention was positively related to attitude toward smoking, which they conceptualized as a post-reception orientation. Related to the current theoretical approach, Rosenthal (2018) found that experiential and instrumental attitudes toward

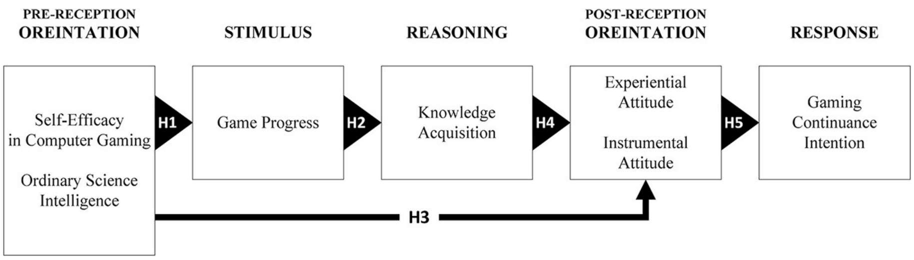

Fig. 1. Hypothetical model.

science videos on YouTube were positively related to the intention to watch more of such videos in the future. Similarly, Sharma et al. (2020) found that gaming continuance intention was positively related to both perceived enjoyment and perceived usefulness. Those perceptions map closely onto experiential and instrumental attitudes, which we predict are related to gaming continuance intention.

H5. Gaming continuance intention is positively related to (a) experiential and (b) instrumental attitudes.

Fig. 1 depicts the constructs and linkages of our hypothetical model.

1.8. Study context

To test our hypotheses, we used the computer game, *Kerbal Space Program*, as a case study. During a 4-h research session, undergraduate students played the game's tutorial missions in a university computer lab at Nanyang Technological University, Singapore. Although the participants were assigned to learn how to play the game, the task focused on learning the game mechanics and not specific scientific concepts. If participants learned science from playing the game, the learning was self-directed and incidental to the gameplay.

For readers unfamiliar with the game, *Kerbal Space Program* simulates a space program set on the fictional Earthlike planet, Kerbin, populated by small green aliens. Players construct rockets part-by-part and send "kerbonauts" on missions within a three-dimensional planetary system comprising a star, five planets, two dwarf planets, and nine moons. It has captivated audiences, with hundreds of thousands of players and generally favorable reviews from both game critics and gamers on forums dedicated to video games in general, not just serious games (Metacritic, 2021). Scientists and astronauts have lauded the game for its accurate portrayal of rocket science, orbital mechanics, and other topics related to space exploration (White, 2014). New players can complete a series of training missions that provide an overview of the game controls and the process of constructing and launching rockets. While completing the missions, players can learn about rocket science and orbital mechanics through experimentation and trial and error. For these reasons, *Kerbal Space Program* is a good context to study the process and outcomes of self-directed learning from playing serious games.

2. Method

2.1. Sample

The site of recruitment was Nanyang Technological University, Singapore, the institution of the lead author, which we selected out of convenience. After obtaining IRB approval to conduct this research, we sent a recruitment email to a random selection of full-time undergraduate student email distribution lists. Each list contains students within a program of study grouped by their year of study. There were 18 selected lists out of 120 total lists, which corresponds to roughly 3500 students. Recipients could fill out an online form to sign up for a study session. Out of 335 students who volunteered to participate, 241 arrived for their session and completed the study.

2.2. Procedure

Each participant came for a single 4-h session. Although the single session limited the amount of time a participant could play the game, there is evidence that considerably shorter gaming sessions can affect attitudes and gaming continuance intention (Gao, 2004; Ruggiero, 2015). At the start of each session, up to eight participants were led into the lab by research assistants. A partition split the lab into two smaller spaces, each containing four Windows PC workstations. The partition was necessary as, at the time of data collection, COVID-19 regulations in Singapore limited gatherings to groups of five. Next, participants completed an online survey,

Table 1
CFA-based constructs and measurement items.

Variable label/item wording	*M* (*SD*)	λ
Self-efficacy in computer gaming (AVE = .51, CR = .75)		
I can keep winning at computer games for a long time.	2.92 (0.97)	.79
I can figure out most computer games.	3.70 (9.74)	.69
No matter how hard I try, I do not do well when playing computer games. (r)	3.41 (0.98)	.65
Experiential attitude (AVE = .80, CR = .89)		
I had an entertaining time.	2.83 (1.21)	.88
The experience was enjoyable.	2.93 (1.17)	.90
Instrumental attitude (AVE = .61, CR = .82)		
I learned something new.	3.93 (0.92)	.78
I had an educational experience.	3.63 (1.02)	.79
The experience was informative.	3.66 (1.05)	.77
Gaming continuance intention (AVE = .77, CR = .91)		
I would like to play more Kerbal Space Program in the future.	2.43 (1.24)	.98
I intend to play more Kerbal Space Program in the future.	2.27 (1.17)	.92
I am not interested in playing more Kerbal Space Program. (r)	2.56 (1.32)	.71

Note. CR = composite reliability. AVE = average variance extracted. *M* = item mean. *SD* = item standard deviation. λ = standardized factor loading. r = reverse-coded item.

which included measures of self-efficacy in computer gaming, ordinary science intelligence, and prior knowledge of rocketry and orbital mechanics. At the end of the survey, there was a short video introducing *Kerbal Space Program* and instructing participants to play through the training missions. Once they began playing, they were free to play as they wished and at their own pace. Because we would re-measure their knowledge of rocketry and orbital mechanics at the end of the session, we instructed the participants not to discuss or look up the answers to the knowledge questions until after the session. Note, the measurement of ordinary science intelligence also comprised knowledge questions, so our instruction ostensibly referred to those questions, too. We did not want to draw too much attention to our interest in their acquisition of rocketry and orbital mechanics knowledge from playing the game.

With 30 min left in the 4-h session, participants were instructed to close the game and complete a follow-up survey. The survey included measures of which training missions the participants completed, post-play knowledge of astronomy and orbital mechanics, experiential and instrumental attitude toward the game, and gaming continuance intention. After completing the survey, the participants received $50 (Singapore dollars) as their participation incentive and were dismissed.

2.3. Measurement

There were two approaches to modeling the constructs, both of which we conducted using Mplus version 8.1. We used confirmatory factor analysis (CFA) to model the common variance among items measuring self-efficacy in computer gaming, experiential and instrumental attitude toward the game, and gaming continuance intention. Table 1 contains the descriptive statistics and factor loadings for each item. It also contains the average variance extracted (AVE) and composite reliability (CR), which should exceed 0.50 and 0.70, respectively (Hair et al., 2014), for each latent construct. We used a two-parameter item response theory analysis (2 PL) to model ordinary science intelligence, game progress, prior knowledge of rocketry and orbital mechanics, and post-play knowledge of rocketry and orbital mechanics. The analysis assumes each construct is unidimensional with respect to an underlying trait (θ), which is a function of two parameters estimated for each measurement item (DeMars, 2010). The first parameter (*a*) indicates how well an item discriminates between high performers and low performers. The second parameter (*b*) indicates how difficult the item was. We extracted predicted θ values for each participant, which we used as a single-item measure of each construct for hypothesis testing. Table 2 through 4 contain information on the items, including the distribution of responses and discrimination and difficulty parameters.

Self-efficacy in computer gaming (CFA). We measured self-efficacy in computer gaming using five Likert-scaled items from Ketelhut (2011). An example is, “I can keep winning at computer games for a long time” and response options ranged from 1 (*strongly disagree*) to 5 (*strongly agree*). During modeling, we removed two items with weak factor loadings ($\lambda < 0.6$) that reduced the construct reliability below the acceptable threshold. After removing those items, the three-item construct had good reliability (Table 1).

Ordinary science intelligence (2 PL). We used a battery of science questions from Kahan (2017), which measure knowledge about basic scientific facts and the scientific method, quantitative reasoning, and cognitive reflection (Table 2). We scored each response 1 (*correct*) or 0 (*incorrect*). This instrument was originally developed using item response theory analysis and we retained the full set of items in our modeling.

Game progress (2 PL). We presented participants with the complete list of 14 training missions and asked them to indicate each ones they completed. We scored each response as 1 (*completed*) or 0 (*not completed*). This is an appropriate measurement to submit to item response theory analysis because the responses are binary and the missions generally increase with difficulty. All 14 items had positive discrimination scores and the difficulty parameter increased linearly with the mission number. Therefore, we retained all the items (Table 3).

Knowledge acquisition (2 PL). We created 10 multiple-choice items concerning terminology and processes related to rocketry and

Table 2
Item response theory analysis of ordinary science intelligence.

Item Label	% correct	Discrimination	Difficulty
Radioactive	91	1.01	−2.65
Lasers	78	0.77	−1.87
Electrons	90	1.03	−2.47
Nitrogen	82	0.43	−1.86
Copernicus	89	0.59	−2.78
Antibiotics	68	1.09	−2.32
Valid	90	1.01	−2.50
Prob 1	98	1.40	−3.53
Prob 2	91	0.52	−4.64
Die	93	1.33	−2.39
Bucks	93	0.37	−6.95
Sweep	81	0.94	−1.80
Disease 1	91	0.92	−2.91
Disease 2	94	0.48	−6.04
Conditional	36	0.61	1.04
Widget	67	1.94	−0.59
Batball	79	0.75	−1.96
Lillypad	62	1.74	−0.44

Note. For item wording, refer to Table 1 in Kahan (2017).

Table 3
Item response theory analysis of game progress.

Training Mission	% completed	Discrimination	Difficulty
1. Getting Started and Basic Construction	99	2.56	−2.97
2. Basic Flight	98	2.95	−2.39
3. Intermediate Construction	97	8.43	−1.93
4. Suborbital Flight	94	2.56	−1.84
5. Advanced Construction	88	2.33	−1.46
6. Go for Orbit	84	4.44	−1.03
7. Orbiting 101	76	5.31	−0.72
8. Science Basics	70	4.22	−0.54
9. To the Mun, Part 1	43	4.74	0.13
10. To the Mun, Part 2	25	4.60	0.64
11. From the Mun	18	3.40	0.96
12. Docking	12	1.52	1.81
13. Asteroid Redirect Mission, Part 1	6	1.65	2.36
14. Asteroid Redirect Mission, Part 2	5	1.48	2.71

Table 4
Item response theory analysis of prior knowledge and post-play knowledge.

Item Label	Prior Knowledge			Post-Play Knowledge		
	% correct	Discrimination	Difficulty	% correct	Discrimination	Difficulty
Apoapsis	42	−0.03	−11.40	81	0.53	−2.94
Prograde	24	−0.11	−11.14	58	0.47	−0.73
Thrusters	16	0.39	4.47	24	0.36	3.26
Latitude	40	0.92	0.53	46	1.46	0.14
Direction	35	1.85	0.53	38	1.61	0.43
Delta-V	41	0.57	0.65	42	0.78	0.47
Hohmann	22	0.32	3.99	19	0.97	1.78
Max-V	25	0.53	2.19	36	0.53	1.19
Baseball	34	0.26	2.56	34	0.47	1.49
Deorbit	19	1.35	1.43	29	0.92	1.14

Note. For detailed item wording, see Appendix.

orbital mechanics, which appear in *Kerbal Space Program*. We scored each response 1 (*correct*) or 0 (*incorrect*). In developing these items, we consulted with a rocket scientist from the Johns Hopkins Applied Physics Laboratory. The main purpose of the consultation was to ensure the scientific accuracy of the items. We measured these items twice, once as prior knowledge and once as post-play knowledge. Because of that, our item response theory analysis needed to holistically reflect both sets of measures. Two items measuring knowledge of terminology had negative discrimination scores in the prior knowledge measure but positive discrimination scores in the post-play knowledge measure. We believe that difference is a result of learning, so we retained all 10 items (Table 4). The average score on the prior knowledge measure was 30%. It increased to 41% on the post-play measure, which was a significant improvement, t (240) = 9.07, $p < .001$. Next, we computed an index of change (Cohen et al., 2003), which corresponded to the variance in post-play knowledge controlling for prior knowledge. An index of change can be used as both an independent variable and dependent variable in statistical analysis (Rosenthal, 2013). And because that index is unrelated to prior knowledge, it provides a good estimation of knowledge acquisition. However, there was evidence that individuals with higher prior knowledge scores performed better on the post-play measures, which is consistent with prior research (e.g., Martin et al., 2019). Although a quadratic function explained only an additional 1% of the variance in post-play score, it was statistically significant ($p < .001$), so we used it to model the index of change. Specifically, the index of change reflected the variance in the post-play score controlling for both the prior knowledge score and the squared prior knowledge score.

Experiential and Instrumental Attitudes (CFA). For this measure, we used five Likert-scaled items adapted from Rosenthal (2018). Two items measured experiential attitude, for example, "The experience was enjoyable." Three items measured instrumental attitude, for example, "I had an educational experience." Response options ranged from 1 (*strongly disagree*) to 5 (*strongly agree*). Using all six items resulted in constructs with good reliability (Table 1).

Gaming continuance intention (CFA). We developed three straightforward measures of intention to play the game more in the future, for example, "I intend to play more Kerbal Space Program in the future." Response options ranged from 1 (*strongly disagree*) to 5 (*strongly agree*) and the construct had good reliability (Table 1).

3. Results

3.1. Measurement model

We used structural equation modeling in Mplus version 8.1 to estimate the hypothetical model. First, we estimated a measurement model to establish latent constructs and generate a correlation matrix among all the variables. We evaluated model fit according to Hu and Bentler's (1999) joint information criteria. They recommended using either CFI >0.95 or RMSEA <0.06 in combination with SRMR <0.08 to achieve a minimum of type II error rates and an acceptable level of type I error rates. We report all three statistics. By this standard, the measurement model had good fit (CFI = 0.980; RMSEA = 0.047, 90% CI = 0.026, 0.066; SRMR = 0.036). This model did not include any post hoc modifications, such as factor cross-loadings or correlated item residuals. Table 4 contains the variances, covariances, and correlations among the variables in the model.

3.2. Hypothesis testing

Next, we estimated the structural model, which retained the factor structure from the measurement model while constraining paths between variables according to the hypothetical model. This model also had good fit (CFI = 0.970; RMSEA = 0.054, 90% CI = 0.036, 0.070; SRMR = 0.07). In support of H1a and H1b, game progress was positively related to self-efficacy in computer gaming (β = 0.26, $p < .001$) and ordinary science intelligence (β = 0.13, $p = .03$). In support of H2, knowledge acquisition was positively related to game progress (β = 0.21, $p < .001$). In support of H3a, experiential attitude toward the game was positively related to self-efficacy in computer gaming (β = 0.21, $p < .001$). Failing to support H3b, instrumental attitude was unrelated to ordinary science intelligence (β = 0.09, $p = .15$). In support of H4a and H4b, knowledge acquisition was positively related to experiential attitude (β = 35, $p < .001$) and instrumental attitude (β = 0.35, $p < .001$). Note, it is not a typo that those regression coefficients were equal to two decimal places. In support of H5a, gaming continuance intention was positively related to experiential attitude (β = 0.68, $p < .001$). Failing to support H5b, gaming continuance intention was unrelated to instrumental attitude (β = 0.03, $p = .77$). Fig. 2 summarizes these results.

3.3. Post hoc analyses

We did not state hypotheses about serial mediation, but the communication mediation model implies that a response happens when a pre-reception orientation triggers stimulus engagement, reasoning, and a post-reception orientation. So, we tested all the indirect paths leading to gaming continuance intention, using 5000 bootstrap samples to estimate confidence intervals. There were four significant indirect paths. Experiential attitude mediated the relationship between gaming continuance intention and self-efficacy in computer gaming (β = .14, 95% CI [0.05, 0.24], $p = .004$; Fig. 3, panel A) and knowledge acquisition (β = 0.24, 95% CI [0.15, 0.36], $p < .001$; Fig. 3, panel B). Extending that latter effect, knowledge acquisition and experiential attitude mediated the relationship between gaming continuance intention and game progress (β = .05, 95% CI [0.02, 0.10], $p = .007$; Fig. 3, panel C). And there was evidence of the fully mediated path, linking self-efficacy in computer gaming, game progress, knowledge acquisition, experiential attitude, and gaming continuance intention (β = 0.01, 95% CI [0.004, 0.03], $p = .056$; Fig. 3, panel D).

Finally, although most participants improved their scores on the knowledge measures, some ($n = 49$) had worse scores after playing. Hypothesis testing showed a positive relationship between game progress and knowledge acquisition, but how much was knowledge acquisition related to the pre-reception orientation? The measurement model showed knowledge acquisition was unrelated to self-efficacy in computer gaming ($r = .09$, $p = .21$) and positively correlated with ordinary science intelligence ($r = 0.15$, $p = .015$; see Table 5). This suggests ordinary science intelligence may be more important for learning. However, the structural model showed game progress mediated the linkage between knowledge acquisition and both self-efficacy in computer gaming (β = 0.06, 95% CI [0.02, 0.12], $p = .02$; Fig. 3E) and ordinary science intelligence (β = 0.03, 95% CI [0.01, 0.06], $p = .052$; Fig. 3F). Those indirect effects suggest both pre-reception orientation variables are related to learning.

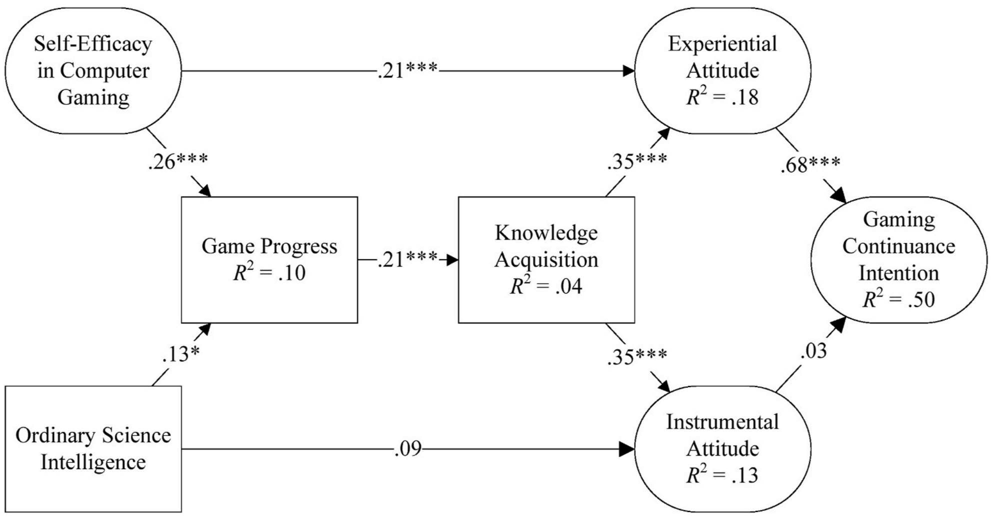

Fig. 2. Standardized paths among CFA-based constructs (ovals) and 2 PL-based constructs (rectangles). *$p < .05$. ***$p < .001$.

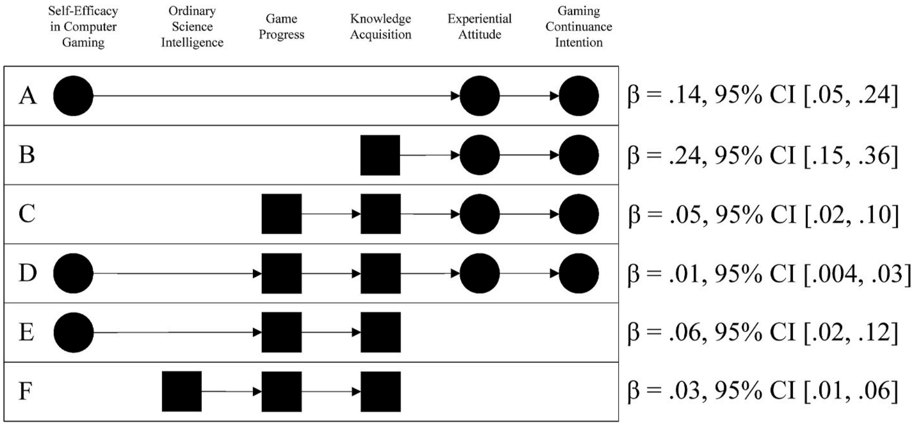

Fig. 3. Summary of indirect effects among involving CFA-based constructs (circles) and 2 PL-based constructs (squares).

Note, two of the effects we reported as significant had *p*-values slightly above the standard threshold of significance. However, their 95% confidence intervals did not overlap zero, which suggests they were statistically significant. At the same time, the effects were small, so regardless of statistical significance, they may lack practical significance. We encourage readers to draw their own conclusions about those findings.

4. Discussion

Whereas prior work has focused on the balance of seriousness and playfulness in game design (Caserman et al., 2020; Hopkins & Roberts, 2015; Jacobs, 2020), the current study suggests there is a similar dynamic within the players. And so, rather than focusing on game design elements that may facilitate learning, we focused on player traits and a series of psychological factors partly defining the process and outcomes of playing serious games. In broad strokes, this involves individuals orienting, attending, and reacting to a stimulus. Within that sequence, individuals may experience motivations to engage with the content and form instrumental and experiential orientations that motivate subsequent engagement with it.

We used the communication mediation model (Cho et al., 2009; Shah et al., 2007) to frame this study. Our results showed linkages among pre-reception orientation, game progress, knowledge acquisition, attitudes toward the game, and gaming continuance intention. We found that players who were well prepared for the gaming side, as reflected in their computer gaming self-efficacy, enjoyed the game more. Players who were well prepared for the serious side, as reflected by their ordinary science intelligence, felt they learned more from the game. And being prepared for both the gaming side and serious side was positively related to game progress. In turn, game progress was positively related to learning, which was positively related to beliefs that the game was enjoyable and educational. Finally, these factors relating to the gaming experience mediated the effects of gaming preparedness on intentions to play in the future. Though, the full serial mediation occurred only on the path starting with self-efficacy in computer gaming and not on the path starting with ordinary science intelligence.

Our findings are also consistent with the idea that performance on learning tasks involves ability and motivation (Van Iddekinge et al., 2017). In the context of science-themed serious games, ability is partly related to gaming skill and general scientific knowledge. Further, these two factors are related to motivation because they orient individuals to seek out certain kinds of media content and, importantly, provide a basis of skills for engaging with the content. Although we did not directly test propositions about the zone of proximal development, the current findings parallel ideas from prior research and help situate our work in the literature. Verma et al. (2019) emphasized the importance of games to support learning in this zone by providing tasks that challenge players without frustrating them with difficulty or boring them with easiness. We did not measure concepts like frustration or boredom, but our findings suggest that players with higher levels of self-efficacy in computer gaming and ordinary science intelligence succeeded in

Table 5
Correlation and covariance matrix of the measurement model.

	1	2	3	4	5	6	7
1. Self-efficacy in computer gaming	0.41	0.12	0.18	0.04	0.22	0.11	0.17
2. Ordinary science intelligence	.23	0.64	0.15	0.08	0.21	0.13	0.11
3. Game progress	.30	.19	0.89	0.12	0.23	0.20	0.20
4. Knowledge acquisition	.09	.15	.21	0.38	0.21	0.13	0.14
5. Experiential attitude	.33	.25	.23	.37	1.13	0.55	0.93
6. Instrumental attitude	.25	.23	.30	.36	.72	0.51	0.47
7. Gaming continuance intention	.22	.12	.18	.19	.72	.54	1.48

Note. The diagonal contains item variances. Covariances are above the diagonal. Correlations are below the diagonal. Correlations larger than 0.13, 0.17, and 0.21 are significant at 0.05, 0.01, and 0.001 alpha levels, respectively.

more challenges, as their game progress evidenced. Recall that we had conceptualized game progress as an indication of engagement (Xiao et al., 2018); thus, individuals oriented to serious games may be more likely to engage with the games and, as a result, have a positive learning experience. This links further with the idea that a positive learning experience can arise when individuals are able to recognize and learn from their failures (Whitton & Langan, 2019), which is a special affordance of games (Toh & Kirschner, 2020).

The current findings also hinted at a broader role of positive affect, namely, in the form of experiential attitude toward gameplay. Although attitude and positive affect are different concepts, attitudes generally have an affective component (Katz, 1960), including in media enjoyment (Vorderer et al., 2004). Klimmt et al. (2009) argued that players will focus on different "fun factors" depending on their level of performance. When performance is high, they derive affective enjoyment out of their good performance and have a more instrumental orientation to the fun factors. When performance is low, they may still enjoy the experience by focusing on things like exploration. This could explain why self-efficacy in computer gaming was related to experiential attitude after controlling for knowledge acquisition. Individuals who are good at games but not good with science can still find the gameplay enjoyable, perhaps mainly for affective reasons. Likewise, non-gamers who are good at science can find the learning process enjoyable, which seems to highlight a more cognitive component of enjoyment. Both kinds of players can develop an experiential orientation to the game.

Enjoyment is also important because it explains a significant portion of gaming continuance intention (Sharma et al., 2020), and in our model enjoyment was the only direct predictor of it. Mediation paths were consistent with the notion that gaming skill and learning performance increase enjoyment, which then makes individuals want to play more serious games in the future. To the extent that enjoyment reflects different fun factors in serious games, with both affective and cognitive aspects, so too will players' desire for more gameplay. It would be interesting to learn from future research if players who are good at either science or gaming, but not both, can grow the other competency through enjoying and playing serious games that are strong in both areas. Such research might draw on the concept of self-scaffolding, where learners use existing high-level skills to support their development of lower-level skills (Mascolo, 2005).

5. Limitations and conclusion

We positioned this study as being about learning outside the classroom. Though it is true there was no coursework or assigned learning objectives associated with playing *Kerbal Space Program*, some features of the task limit the study's ecological validity. Study participants were students at a university where the lead author teaches, the research lab is located on campus and in an academic building, and the students answered questions measuring their scientific knowledge. These factors may have resulted in implicit learning objectives. One mitigating factor is that research assistants conducted the study sessions and the lead author interacted with study participants only when trouble-shooting things like the game not loading properly. So we feel participants engaged at least in self-directed learning (Toh & Kirschner, 2020). Even so, the gameplay did not happen in a natural setting. Participants were invited to play at their own pace, but they did not have any alternative activities they could choose. It was a forced introduction of a captive audience to *Kerbal Space Program*, and it is unclear how many participants would choose to play it in their free time at home. Further, we tested our model using a singular student sample and a singular game, so the present study design does not provide evidence that the findings would generalize to other populations or other serious games that are as successful and popular as *Kerbal Space Program*. Notably, most students at Nanyang Technological University are citizens of Singapore, a country that consistently performs well in mathematics and science in the Program for International Assessment (PISA) study by the Organization for Economic Co-operation and Development (OECD, 2019). Because the game touches on mathematical and scientific concepts, the national context of this study limits generalization to other populations. Hence, future research should address similar research questions as this study, using more informal learning settings, more diverse populations, and a wider variety of serious games.

We should also note two potential limitations of our measures. First, we measured game progress using a self-report measure of mission completion. This measure is imprecise because it is subject to errors in recall (e.g., participants may have misremembered completing a mission) and did not measure activities within missions. For example, it would have been useful to know in early missions the number of failed rocket launches. Though, our item response theory analysis provided information on the difficulty of each mission relative to the others, so we feel our measure of game progress was adequate albeit imperfect. Second, our measures of self-efficacy in computer gaming, experiential attitude, instrumental attitude, and gaming continuance intention used a small number of items. The problem with using few items is that a construct might not capture the nuances of the underlying concept (Ornstein, 2013). In contrast, it is possible to measure a unidimensional concept using a single item; though, a single-item measure precludes tests of reliability (Ornstein, 2013). The current study measured constructs that, according to prior research, are unidimensional. By following prior research, we had some confidence in the validity of the measures. By using more than one item to measure each construct, were able to assess measurement reliability.

These limitations notwithstanding, the present study offers a valid test of the communication mediation model in the context of serious games. Individuals who play a serious game, even for a short while, may gain new knowledge and orient themselves more to the instrumental or experiential aspects of the game. That process may depend on their prior orientations and may motivate them to play the game more in the future. One practical takeaway, then, is that evaluations of serious games need to account not only for what players learned, but also if they enjoyed their time playing. Computer games like *Kerbal Space Program* seem to succeed in both respects, launching into the education space of inquisitive minds.

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Credit author statement

Sonny Rosenthal: Conceptualization, Funding acquisition, Methodology, Resources, Project administration, Investigation, Supervision, Data curation, Formal analysis, Writing – original draft, Visualization. **Rabindra Ratan**: Conceptualization, Methodology, Writing – original draft.

Declaration of competing interest

We have no competing interests to report.

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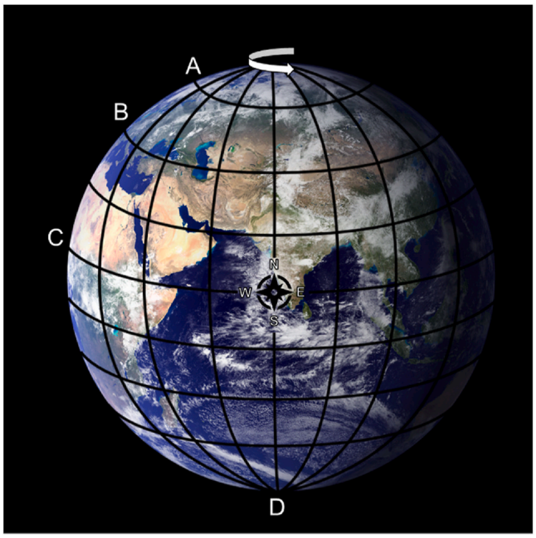
Appendix

This appendix contains the items used to measure prior knowledge and post-play knowledge. The item labels are indicated in brackets and the correct answers are underlined.

[Apoapsis] To what does the term “apoapsis” refer?
It is the highest point of an elliptical orbit. (correct)
It is a path perpendicular to the Equator.
It is the point in the sky directly upward.
It is the distance to the visible horizon.
[Prograde] To what does the term “prograde” refer?
It is the forward direction along a flight path. (correct)
It is the backward direction along a flight path.
It is flight path angled above the horizon.
It is a flight path angled below the horizon.
[Thrusters] In which of the following situations would it be most appropriate to use the RCS thrusters on a spacecraft?
While docking with another spacecraft in orbit. (correct)
During the first stage of rocket’s ascent.
During the final moment of a parachute landing.
While decelerating from an orbit for reentry.

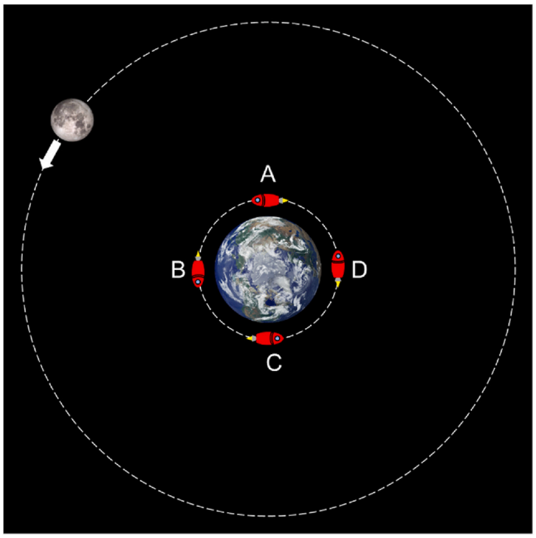


The Earth rotates on its axis as indicated in the image above. The image also indicates four different lines of latitude. For the next two questions, imagine you need to launch a rocket into Earth’s orbit, and you need to figure out the most fuel-efficient way to do so.

[Latitude] From which latitude would you want to launch the rocket?
Latitude A
Latitude B
Latitude C (correct)
Latitude D

They are all equally efficient.
[Direction] Imagine the rocket is to be launched from a site on Latitude C. What direction would be ideal for the launch?
North
South
East (correct)
West

The direction doesn't matter.
[Delta-V] Which of the following trips involves the largest change in speed?
Starting on Earth's surface and traveling to low-Earth orbit (correct)
Starting from low-Earth orbit and traveling to an orbit of the Moon
Starting from an orbit of the Moon and traveling to the Moon's surface
Starting on the Moon's surface and traveling to an orbit of the Moon



The image above shows a view of the Earth's North Pole with the Moon and a spaceship both orbiting in an anti-clockwise direction. Note, this image is not to scale.

For the next few questions, imagine you and a friend are in the spaceship. You are in a low-Earth orbit and traveling at several thousand kilometers per hour. Your ship has a special engine that allows you to increase your speed instantaneously in the direction the ship is pointed.

[Hohmann] You wish to travel to the Moon and need to use the ship's engine to get there. You may point the ship in any direction, but you may use the engine only a single time and cannot orbit the Earth more than once before reaching the Moon. For the most fuel-efficient trip, where should you use the engine?
Point A
Point B
Point C
Point D (correct)

They are all equally efficient.
[Max-V] After firing your engine, you are on your way! Where on your journey will your ship be traveling at the fastest speed relative to the Earth?
When it is near the Earth (correct)

When it is half-way to the Moon
When it is near the Moon
The speed doesn't change

[Baseball] After visiting the Moon, you fly the ship back into Earth's orbit and are now at Point A. Your friend brought a baseball, so you don your spacesuits and go outside to play catch. Your first throw is wide, flying past your friend at 50 km/h. Coincidentally, you have thrown it directly toward the Moon, roughly 400,000 km away. After one year has passed, what is the most likely location of the baseball?

Orbiting around the Earth (correct)
Resting on the Moon's surface
Orbiting around the Moon
Traveling out of the Solar System

[Deorbit] Imagine you are at Point A and wish to return to the Earth's surface. For the most fuel-efficient trip, in what direction should you point the ship when you use the engine?

Forward in the same direction of your orbit
Backward in the opposite direction of your orbit (correct)
Directly up, away from the surface of the Earth
Directly down, toward the surface of the Earth

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