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It's Contagious! Examining Gamified Refutation Texts, Emotions, and Knowledge Retention in a Real-World Public Health Education Campaign

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ABSTRACT

The current study investigated the relations between gamified refutations of COVID-19 misconceptions and individuals' emotional reactions and knowledge retention within a large-scale public health education campaign. Refutations have a substantial body of evidence supporting their use to correct misconceptions, yet reduced efficacy has been observed for some topics that generate negative emotional responses. We tested whether gamification could mitigate these limits given that it capitalizes on positive affective engagement. From May to December 2020, approximately 200,000 individuals were recruited from social media in Canada to engage with a nongame interactive survey as a control or a fully gamified platform focused on correcting COVID-19 misconceptions. Gamification was associated with a greater number of happiness and anxiety responses and fewer responses of anger and skepticism in reaction to having misconceptions corrected by refutations. Further, participants who engaged with gamified refutations retained correct information after a brief period. Finally, happiness and anxiety were positively associated with and anger and skepticism were negatively associated with retention of refutation information and support for related public health policies. Implications for scaling up and reinforcing the benefits of refutations for public engagement with science are discussed.

Introduction

Traditionally, governments and related organizations rely on direct broadcasts of key information via print, television, or online media to educate their citizens on issues in the public interest (Hofmann et al., 2013). However, the public may have misconceptions about several of these subjects, such as immigration, climate change, and pandemics, which both undermine informed decision making and are often unaffected by a simple broadcasting strategy (Carey et al., 2020). Thus, new methods of communicating and engaging with the public are needed to address misconceptions and empower informed actions.

In the following, we investigated the effects of embedding refutation texts into a digital gamified environment. Refutation texts are one well-known tool to correct misconceptions in traditional educational settings (Schroeder & Kucera, 2022), yet challenges exist to scaling them up to address public misconceptions within present-day debates among large, diverse audiences. We describe the potential of gamification as a novel approach to address these challenges and capitalize on individuals' inherent motivational and emotional strengths. We tested this approach to correcting misconceptions

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against the backdrop of the COVID-19 pandemic, which spawned many new misconceptions and presented a historic challenge to traditional communication efforts (Cinelli et al., 2020; Tangcharoensathien et al., 2020).

Infodemic context

The novel coronavirus pandemic generated unprecedented global attention and concern (WHO, 2020). The gap between what little was known early on about its risks, symptoms, transmission, prevention, and treatments and what individuals desired to know was filled with rapidly evolving scientific evidence and government policies along with estimates and predictions, rumors and speculation, and mis- and disinformation. For instance, an analysis of the most viewed YouTube videos on COVID-19 found that one in four contained false information, which together had already garnered 62 million views by March 2020 (Li et al., 2020). The sum of this informational surge led the WHO Director-General to state in February 2020 that "we're not just fighting an epidemic; we're fighting an infodemic" (WHO, 2020, para. 45). *Infodemics* are an overabundance of information, including false information, during a disease outbreak that leads to confusion, mistrust, and potentially dangerous behaviors (WHO, 2021). As such, research was needed that not only countered misinformation but also captured attention of a broad audience within the context of an ongoing infodemic.

Additionally, the infodemic is in part driven by the fact that public health issues are emotionally charged and value laden. Facing a barrage of news reports about an infectious disease pandemic and the disruptions it wrought is anxiety-provoking (Abadi et al., 2021; Neill et al., 2021), and anxiety itself in turn drives greater information-seeking (Jungmann & Witthoft, 2020). Further, despite in many cases being necessary, several public health responses to the pandemic still severely disrupted individuals' economic, social, and personal lives. As a result, multiple stakeholders held conflicting incentives and ideas about the high-stakes issue of the best course of action, which frequently led to politicization and angry confrontations based on competing values (Gadarian et al., 2021; Pew, 2021; Smith et al., 2021; Trevors & Duffy, 2020). Taken together, the infodemic and the strong emotional reactions it elicited presented a historic challenge to public health communication, which provided space for misconceptions to proliferate and necessitated new approaches to public education (Han et al., 2020; Li et al., 2020).

Belief change via refutation text

Refutation texts are an effective, short-term, and adaptable countermeasure to misconceptions that have strong theoretical and empirical support. Refutations are typically brief documents with a specific text structure that explicitly references an incorrect belief, refutes it, and presents several claims that reinforce the correct understanding as a substitute explanation (Hynd, 2001) . In so doing, Kendeou and colleagues (Kendeou et al., 2019; Kendeou & O'Brien, 2014; Kendeou et al., 2013) theorized that refutation texts promote a specific sequence of cognitive processes that result in knowledge revision. Most notably, this includes instigating competitive cognitive conflict between correct and incorrect understandings. Conflict is resolved when the quantity and quality of correct supporting explanations presented in refutations is encoded in and dominates the same memory network as the original incorrect belief. After reading a refutation text, outdated incorrect beliefs no longer intrude in recall or decision-making tasks since limited attention is privileged for the newly constructed, dominant correct conception.

With few notable exceptions, empirical research on refutations largely supports this theoretical account. At the point of contradicting a misconception, refutations are found to trigger cognitive conflict and epistemic emotions of surprise, curiosity, and confusion (Kendeou et al.,

2019, 2013; Trevors, 2021; Trevors et al., 2017), which are associated with detecting and resolving knowledge inconsistencies via greater informational seeking, critical thinking, and elaborative learning processes (D'Mello et al., 2014; Foster & Keane, 2019; Muis, Chevrier et al., 2018; Muis, Sinatra et al., 2018). Refutations are associated with higher levels of epistemic judgments regarding the plausibility, credibility, and quality of refutational evidence, which in turn predict revising incorrect beliefs (Flemming et al., 2020; Lombardi et al., 2016; Muis et al., 2020). Additionally, refutations increase metacognitive awareness of the conflict between old and new interpretations and of individuals' own understanding (Mason et al., 2017; Pieschl et al., 2021; Prinz et al., 2019), which are integral processes in changing prior beliefs (Vosniadou et al., 2001). As a result of these cognitive, affective, and metacognitive processes, refutations are consistently associated with gaining more accurate knowledge as well as other positive changes in related attitudes and policy support (Aguilar et al., 2019; Thacker et al., 2020; Tippett, 2010; Walter & Murphy, 2018).

However, for several other topics and groups of individuals, refutations and related fact checks are less effective. This is possibly due to distinct sets of motivational and emotional reactions. Despite improving the accuracy of the average individual's beliefs, meta-analytic studies show that the effect of refutational-like fact checks is weaker for real-world misconceptions, political topics, and counter-attitudinal corrections (Walter et al., 2020; Walter & Murphy, 2018). The reduced efficacy in these areas suggests that not all individuals are engaging in rational belief updating processes when refutations are applied to topics that are emotionally charged or touch on personally relevant values. Two routes that implicate different motivational and emotional processes may explain these diminished refutational effects.

First, in such cases where an individual perceives that their values are under threat, they may be inclined to engage in *motivated reasoning*, a well-studied phenomenon in which individuals use their intellectual abilities to protect their valued beliefs at the expense of forming accurate beliefs (Kaplan et al., 2016; Lodge & Taber, 2013). Affective theory suggests that emotions occur in response to relevant stimuli and have tendencies to motivate subsequent actions (e.g., flight or fight), such as anger in response to perceived violations of moral values and desire for retribution (Haidt, 2003). Indeed, in belief change research, corrective messages perceived to threaten valued beliefs have been found to lead to doubt, anxiety, and anger, which in turn predicted maintaining false beliefs by rejecting corrections (Trevors et al., 2016; Nauroth et al., 2014, 2015; Trevors, 2021; Trevors & Duffy, 2020).

Second, individuals may be motivated to avoid engaging with refutational message at all. Some topics like climate change or pandemics provoke fear, anger, or despair (Manning & Clayton, 2018; Renström & Bäck, 2021); many individuals do not enjoy interacting with political topics (Klar et al., 2018); and all conflicts with prior beliefs are inherently unpleasant (Dignath et al., 2020). Together, refutations of emotionally charged or politicized topics have low *hedonic utility*, a condition in information-seeking theory that asserts that, all else being equal, individuals will be motivated to avoid information that induces unpleasant affect (Sharot & Sunstein, 2020).

In sum, these differing sets of negative emotional reactions to refutations are clearly problematic for belief change interventions. Learning from refutations is typically successful and associated with higher positive emotions and lower negative emotions (Broughton et al., 2013; Heddy et al., 2017; Thacker et al., 2020). In contrast, there may exist multiple negative affective pathways that blunt the effectiveness of refutations on emotionally charged and value-laden topics. This is troubling because these same topics often represent some of the most significant and urgent issues facing society, such as climate change or vaccinations, where consensus on factual information is a prerequisite for collective actions. Thus, with the goal of enhancing and extending the benefits of refutations to more topics and individuals, we explored whether timely and critical corrections could be effectively delivered, and negative affect mitigated, by gamifying a belief change intervention.

Adaptive affective engagement via gamification

Gamification refers to the process of adding elements and mechanics of game play (e.g., challenges, competition, progress, feedback) into traditional educational contexts to take capitalize on individuals' inherent motivational and emotional strengths (Deterding et al., 2011; Sailer et al., 2017; Sardi et al., 2017). Gamification fosters intrinsic motivation and positive affect (e.g., enjoyment, interest; Mullins & Sabherwal, 2018), which can promote attitude change under both low and high cognitive elaboration conditions (Petty & Briñol, 2015), and supports individuals' needs for autonomy since the process proceeds under their control (Ryan & Deci, 2017). As such, it stands in contrast to traditional direct routes of persuasion that may be perceived as overly controlling (Steindl et al., 2015). As a result, gamified platforms have been shown to promote learning as well as changes in beliefs and behaviors (Alahäivälä & Oinas-Kukkonen, 2016; Hamari et al., 2016). Moreover, gamification may represent a new approach to public engagement with science and technology that challenges traditional knowledge deficit models of communication (Simis et al., 2016; Suldovsky, 2017). In the latter, science communication is viewed as a process of transmitting facts that are assumed to be invariantly interpreted by the public, and the persistence of misconceptions reflects the need for more information or irrational beliefs that block rational updating (Nisbet & Scheufele, 2009). In contrast, a digital gamified approach may offer personalized and positive interactions between individuals and science content beyond the capacity of traditional communication efforts, dynamically adapting to individuals' behaviors and responses and thus potentially enriching public engagement and informed decision-making overall (Baram-Tsabari & Schejter, 2019).

There is a long history of applying gamification to augment learning, but recently it has also been successfully used to proactively prevent the formation of false beliefs from online misinformation with digital literacy training. Roozenbeek, van der Linden, and colleagues (Basol et al., 2020; Maertens et al., 2020; Roozenbeek & van der Linden, 2019) found that participants recruited through a university press release and BBC news coverage were better able to recognize unreliable news items after playing a game that exposed them to common strategies used in creation of misinformation. Although a useful tool as a part of a multilayer defense against misinformation (Van der Linden, 2019), preemptive debunking may not be relevant for specific misconceptions once formed. Further, samples in this research were recruited from reputable news sources and often skewed toward younger, liberal, and well educated. In contrast, individuals susceptible to misinformation tend to be older, conservative, less educated, and obtain their news from less reliable sources such as social media (Brashier & Schacter, 2020; Guess et al., 2019; Pan et al., 2021; Yang et al., 2021).

In sum, given the potential for direct refutations to trigger motivated reasoning and/or low hedonic utility among some individuals and topics, a direct broadcast of corrections is not likely to attain optimal success, allowing critical misinformation to persist. Thus, there is promising potential to transfer gamification benefits to belief change interventions. Further, there is also an opportunity to test this proposition directly on social media platforms, which are a more naturalistic context to support populations vulnerable to misinformation.

Current study

The purpose of the current research was to empirically test the assumption that gamification of refutations supports adaptive cognitive and emotional engagement that is positively linked to learning within a large-scale, naturalistic context. This assumption was tested with a real-world public health education campaign that used a novel digital game focused on combating several COVID-19 misconceptions, which was widely distributed in Canada in 2020. Three research questions were addressed:

(1) Do individuals retain gamified refutation information in memory?
(2) Is gamification associated with an increase positive and decrease negative emotions?
(3) Are emotional reactions to gamified refutations related to knowledge retention and support for related public health policies?

Methods

Materials and procedure

Interactive survey control

Participants were recruited to engage with one of two online data collection platforms. An interactive online survey (https://coronavirus.publicsquare.digital) was distributed to both assess the prevalence of misconceptions among the public and emotional reactions within a non-gamified context. The survey consisted of a possible two dozen true and false claims about COVID-19 and asked participants to indicate whether they believed each was true or false. Immediately following and conditional on their response, participants received interactive and corrective feedback ("Correct!" or "Wrong") and brief explanation that followed refutation design principles to include multiple reinforcing facts (Kendeou & O'Brien, 2014; Kendeou et al., 2013). Additionally, after incorrect responses and refutational feedback, participants were asked "How does this information make you feel?" and given four labeled emoji to choose from: "Happy," "Angry," "Anxious," and "Skeptical." Refutations were carried forward to the full gamified intervention if either of two conditions applied: (1) the research team determined there were meaningful levels of incorrect responses (e.g., <90% correct on a particular claim), indicating possible presence of misconceptions,[1] or (2) if the medical epidemiologist on our research team determined that if individuals were to act upon a particular misconception posed serious risk to individuals or communities (e.g., reliance on alcohol to disinfect oneself or on herd immunity as a safe mitigation strategy).

Digital game design

The design of *It's Contagious!* (https://itscontagiousgame.com; Figure 1) followed gamification design principles to motivate and positively engage participants via game elements and mechanics: playful design, specific goal, challenge, personalized experience, visible progress, rapid feedback, freedom of choice, and accrual grading (points; Deterding et al., 2011). Participants played through the digital game on desktop or mobile devices and progressed through a possible two dozen content pages ("cards"), each presenting one prevalent misinformation or fact about COVID-19 (e.g., "COVID-19 has caused fewer deaths than the flu (influenza) would typically cause in a year" [false]). COVID-19 misconceptions were identified from the control survey, news reports, and social listening (i.e., collecting data from various social media platforms and forums on a set of topics and key terms related to COVID-19 misconceptions).

Refutation and retention. Participants were asked to indicate their belief in the veracity of the COVID-19 claims by selecting one of two options: true or false. The following screen presented immediate feedback on their response, which followed evidence-based practices for robust misinformation correction (Kendeou & O'Brien, 2014; Kendeou et al., 2013), including refutation and accessible explanation that reinforced the best available scientific evidence obtained from expert sources (e.g., CDC). Correct responses were recorded as 1s and incorrect responses as 0s and averaged across all cards responded to for analysis. Refutations and corrective explanations were vetted by the medical epidemiologist for accuracy and completeness. As a measure of knowledge retention, after several cards had been responded to, participants were asked to respond to a repeated presentation of a question they originally answered

Figure 1. Screenshots of a sequence in the gamified intervention.

incorrectly with the prompt "Do you remember?" followed by the original claim below. The same true or false response options were available for this knowledge retention question and correct or incorrect responses likewise received a score of either 1 or 0, respectively.

Emotional reactions, policy support, and demographics. Points displayed on a scoreboard were awarded or removed for correct and incorrect responses. Depending on point totals, players may go up or down eight ranks (i.e., "Newb" to "Genius"). Importantly, participants could recover a lost rank by responding to additional questions, which included emotional reactions to refutations via emoji rating scale (i.e., happy, angry, anxious, skeptical) and support or opposition to several public health policies (e.g., face mask mandates) measured on a five-point Likert scale. Recovery questions were prefaced with the following message: "Recover your rank! There's no right or wrong answer to the following questions. Please just answer honestly!" Finally, participants could opt into self-disclosing demographic details (i.e., age, gender, race, and ethnicity). All game measures have been made publicly available via the Open Science Framework (OSF) and can be accessed at https://osf.io/nm4ej/

Sample

From May to June 2020, participants were recruited to engage with an interactive online survey that served as a nongamified control. Participants were recruited from advertisements on social media platforms in Canada and were not paid. During this time, 19,493 unique sessions were initiated, from which 11,486 individuals answered at least one knowledge question and 7,831 provided emotional reactions. Only aggregated demographics from a subsample (n = 1,163) of survey participants who opted in were recorded as we prioritized collecting responses to knowledge and emotion questions in the survey, which are presented in Tables 1 to 3. From August to December 2020, participants were recruited via the same method to play the fully gamified intervention and were not paid. During this time, 180,384 unique sessions were initiated that provided an answer at least one knowledge question, 67,094 answered a repeated knowledge

Table 1. Self-reported race and ethnicities.

	Survey		Game	
Category	*n*	%	*n*	%
First Nations	48	4	268	1
Inuit	17	1	21	0
Métis	29	2	232	1
East Asian	88	6	435	2
South Asian	71	5	321	1
Southeast Asian	73	5	277	1
Black/African	67	5	90	0
Black/Caribbean	45	3	85	0
Black/North American	32	2	37	0
Latin American	45	3	199	1
Latinx	19	1	30	0
White/European	333	24	7071	28
White/North American	558	41	14,158	57
Middle Eastern	52	4	148	1
Mixed Heritage	110	8	745	3
I don't see myself represented here	N/A	N/A	516	2
Abstain	68	5	292	1

Table 2. Self-reported gender.

	Survey		Game	
Category	*n*	%	*n*	%
Female	682	50	18,549	70
Male	602	44	6952	26
Nonbinary	27	2	163	1
Gender expansive	19	1	34	0
Other	N/A	N/A	240	1
Two-spirit	24	2	46	0
Transgender	19	1	54	0
I don't see myself represented here	N/A	N/A	139	1
Transsexual	13	1	10	0
Genderqueer	20	1	72	0
Intersex	8	1	7	0
Abstain	25	2	202	1

Table 3. Self-reported age.

	Survey		Game	
Category	*n*	%	*n*	%
18–24	215	18	1928	7
25–34	185	16	2523	10
35–44	151	13	2945	11
45–54	175	15	3969	15
55–64	164	14	7230	28
65–74	143	12	5819	22
75–84	38	3	1276	5
85+	44	4	199	1
Abstain	46	4	350	1

question, 22,829 provided emotional reactions, 37,240 responded to at least one policy question, and approximately 26,000 opted in to partially or fully disclose their demographic information at the end of the game (Tables 1–3).[2]

Table 4. Descriptive and correlational statistics between knowledge, emotion, and key outcomes within the gamified platform.

	Prior Knowledge	Happy	Angry	Anxious	Skeptical	Retention	Policy Support
Prior Knowledge	.79 (.27)						
Happy	.157**	.34 (.46)					
Angry	−.119**	−.228**	.09 (.28)				
Anxious	.051**	−.518**	−.233**	.34 (.46)			
Skeptical	−.154**	−.386**	−.168**	−.392**	.23 (.40)		
Retention	.265**	.080**	−.054**	.013	−.069**	.87 (.34)	
Policy Support	.235**	.150**	−.071**	.105**	−.242**	.102**	.83 (.24)

Note. Means and standard deviations (in parentheses) on diagonal. Scale, 0–1.
** $p < .01$

Results

Descriptive and correlational statistics between primary study variables are reported in Table 4.[3] The number of correct responses to questions were averaged as a measure of participants' prior COVID-19 knowledge. The proportion of emotional reactions across all content was extracted for each of the four emotions. Finally, public health policy support across several policies was averaged into a single value. All data have been made publicly available via OSF and can be accessed at: https://osf.io/nm4ej/

Knowledge retention from gamified refutations

To answer the first research question whether individuals retain gamified refutation information, responses to the repeated question were analyzed. Of the 67,094 players who provided a response to a repeated question that they initially answered incorrectly, approximately 87% provided the correct response. A one-sample t test showed that this level of performance was significantly higher than chance (i.e., 50%), $t(67{,}093) = 283.32$, $p < .001$, $d = 1.09$, which reflects large effect of retention of refutation information.

Effect of gamification on emotional reactions

To answer the second research question whether gamification led to an increase in positive and decrease in negative emotions, we compared average proportional emotional responses to refutations between control survey and gamified conditions (Table 5). Given the differences in content between conditions, only emotional reactions to 13 refutations that were consistent between control and gamified platforms were analyzed for differences. Compared to the nongamified control survey,

Table 5. Difference between survey control and game conditions on proportional emotional reactions.

Emotion	Condition	*M*	*SD*	*t*	*df*	*p*	*d*
Happy	Survey	36%	40%	3.04	22,909	.002	.042
	Game	38%	48%				
Angry	Survey	12%	27%	−5.91	22,909	<.001	−.082
	Game	10%	29%				
Anxious	Survey	23%	35%	11.55	22,909	<.001	.160
	Game	29%	45%				
Skeptical	Survey	29%	38%	−11.04	22,909	<.001	−.153
	Game	23%	41%				

Table 6. Relations between prior knowledge and emotional reactions to subsequent knowledge retention and policy support.

Predictor Variable	Outcome Variable Models					
	Retention			Policy Support		
Step 1	β	*b* (95% CI)	*t*	β	*b* (95% CI)	*t*
Prior knowledge	**.19**	**.50 (.46-.54)**	**25.61*** **	**.25**	**.39 (.37-.41)**	**38.60*** **
Step 2						
Happy	**.05**	**.04 (.03-.05)**	**6.90*** **	**.11**	**.06 (.05-.07)**	**17.35*** **
Anger	**−.03**	**−.04 (−.06–.02)**	**−4.44*** **	**−.04**	**−.04 (−.05–.02)**	**−6.37*** **
Anxious	.00	.00 (−.01-.01)	.17	**.09**	**.05 (.04-.05)**	**14.29*** **
Skepticism	**−.04**	**−.03 (−.05–.02)**	**−5.04*** **	**−.21**	**−.12 (−.13–.11)**	**−32.36*** **

Note. CI = confidence interval. Bolded values denote statistical significance.
*** $p < .001$

happy and anxious reactions were higher and anger and skepticism were lower in the digital game intervention (absolute Cohen's *d* values ranged .04 to .16), which held true after controlling for prior knowledge (*p*s < .005). These results suggest that gamification was largely associated with increased positive and decreased negative emotions on the same refutation content, with an increase in anxiety in the gamified condition as an exception.

Relations between emotions and key outcomes

Finally, to answer the third research question whether emotional reactions to refutations were related to retention and support for related policies, in separate hierarchical linear regressions we regressed retention and policy support on correct responses in the first step and happy, anger, anxiety, and skepticism separately in second steps. Regression statistics are reported in Table 6. Average number of correct responses as a measure of prior COVID-19 knowledge was a positive predictor of overall retention and policy support in the first step. Beyond the effect of prior knowledge, happiness was a consistently positive predictor of retention and policy support and; anger was a consistently negative predictor of retention and policy support; likewise, skepticism negatively predicted retention and policy support and anxiety was a positive predictor of policy support only. Across regressions, with the exception of anxiety, the addition of emotions into regression models resulted in significantly improved predictions of retention (ΔFs(1, 18,590) = 19.69–47.61, *p*s < .001) and all emotions improved predictions of policy support (ΔFs(1, 22,162) = 40.60–1044.88, *p*s < .001).[4] These results indicate that beyond the large effect of prior knowledge, emotional reactions to gamified refutations significantly and uniquely related to correct information retention and policy support.

Discussion

The present study investigated the relations between emotional reactions to gamified refutations, knowledge retention, and support for public health policies within a large-scale public health campaign. Refutations have a substantial body of evidence supporting their use to correct misconceptions. However, reduced efficacy is observed for emotionally charged or value-laden topics that reflect some of the most urgent issues facing society, possibly due to negative emotional reactions to refutations. We proposed that gamification could mitigate these limits given that it capitalizes on positive affective engagement. The current results provide preliminary support for this overall contention. Namely, compared to a traditional survey, gamification was associated with a higher proportion of happiness and anxiety and lower proportion of anger and skepticism in reaction to having one's misconceptions corrected by refutations. Participants who engaged with gamified refutations were able to retain correct information after a brief period, suggesting they are at minimum attending to the educational

basis of the game. Finally, happiness and anxiety were positively related to and anger and skepticism were negatively related to knowledge retention and support for related public health policies.

Refuting misconceptions with digital games

Participants showed a large effect of retaining refutations in memory that were embedded into a gamified context. Further, with some caveats, gamified refutations were associated with a larger proportion of positive emotional reactions and a generally smaller proportion of negative emotional reactions compared to the same refutations in a non-gamified survey. These results are noteworthy considering recent meta-analyses showing diminished (although still often significant) effects of refutations and fact checks on real-world, politicized, or counter-attitudinal topics (Walter et al., 2020; Walter & Murphy, 2018). We theorized that reduced efficacy may be due to either motivated reasoning to protect valued, albeit though inaccurate, prior beliefs or low hedonic utility, leading people to avoid engaging with unpleasant corrections on sensitive topics. The current results therefore are a demonstration that gamified refutations may be an effective alternative to correcting misconceptions on such topics. Roughly 9 of 10 players were able to correctly recall newly presented true information about COVID-19 when prompted after several new rounds of questions, which suggests that refutation information was successfully stored and not simply maintained in working memory. Recall that retention questions were only asked for a question that participants initially provided an incorrect response, indicating that participants either held a misconception or did not know the answer. As such, this finding indicates that the current gamified refutations increased retention of accurate knowledge from participants' initial baseline. However, this effect may be moderated by the strength of individuals' prior beliefs, as more strongly held or elaborate misconceptions require additional intervention for their revision (Chi, 2013). Additionally, to recruit a large, naturalistic sample by reducing participant drop-off, knowledge retention was embedded within the intervention to minimize disruptions to game flow, yet the nature of this measure does not answer questions about the durability of knowledge retention and higher forms of learning. In sum, although future research should further explore the precise nature of prior beliefs and the longer-term duration of knowledge acquisition, the present results show an early and promising potential to efficiently educate the public on a large scale with digital games and addresses calls to broaden the audience for corrective messages (Nyhan, 2021).

Further, we found that positive and negative emotional reactions to refutations were significantly associated with subsequent retention and policy support beyond the large effect of prior knowledge. This supports our central contention that increasing positive engagement and decreasing negative affective engagement of belief correction content via gamification may be important and opposite drivers of promoting uptake of accurate information on controversial socioscientific content. Interestingly, anxiety was found to have a unique pattern of relations among outcome variables distinct from other negative emotions since it was positively related to support for public health policies. Despite being a negative activating emotion, (e.g., subjectively unpleasant and high in arousal), anxiety has a complex relationship to learning outcomes as it has been linked to both approach and avoidance motivation and desired and undesired outcomes (Pekrun, 2006). In the current context focused on COVID-19, higher anxiety has been found to predict engagement in more public health-compliant behaviors (e.g., hand washing and social distancing; Harper et al., 2021). Higher anxiety may therefore reflect a recalibration of perceived risk from the pandemic rather than a reaction to refutations per se. That is, corrective information about the severity and susceptibility of COVID-19 may have led players to become less complacent about disease risk and form more accurate perceptions of disease risk. Along with happiness, anxiety was found to be higher in the gamified platform, although it should be noted that happiness was still the predominant emotional experience. Given that the refutation content was identical between survey and gamified conditions for statistical comparison, greater responses of anxiety may be attributed to an increase level of attention to the

content in the gamified condition (and thus greater revision of risk perceptions) versus a relatively shallower level of attention in the survey control. However, speculations on cognitive engagement during game play require future investigation. Further, it may not be the case that gamification changed topic-specific emotional responses to the pandemic. Rather, participants' situation-specific emotional experiences might have changed because of differences between traditional informational presentation and gamified presentation. Such a positive situational change may allow individuals to consider refutational information less biased by negative emotional reactions that have been previously linked to poor learning outcomes (Trevors & Duffy, 2020).

Limitations and future directions

The results of this research are limited in several ways. First, given that it was an evaluation of a real-world public health education campaign, the number of assessments were kept to a minimum to reduce participants early exit from the intervention. As such, several potentially relevant individual variables, including educational level and political ideology, were not presently assessed but should be included in future research to improve our understanding of potential moderators of revising misconceptions. There is likely important heterogeneity within our sample, the contexts in which they engaged with the intervention, and observed effects, which ought to be further explored (Bryan et al., 2021). Further, intervention content was presented randomly, and order of presentation was not recorded in this study, but future research may gain additional insights by mining sequential patterns in participants' behaviors, responses, and emotional reactions (e.g., specific sequences of refutations that predict drop off or knowledge retention). Second, although the current knowledge retention question similarly minimized disruptions to game flow, other measures of learning should be explored in future research that allow for evaluation of higher forms beyond retention (e.g., comprehension, application) and the robustness of learning (e.g., delayed posttest; Shute, 2011). Additional outcome measures may be especially relevant for interventions that seek to revise misconceptions, as such efforts may involve persuasion or changes in attitudes as well as changes in knowledge (Sinatra & Seyranian, 2015). Third, there may be differences between individuals who opted to complete the survey or gamified intervention and those that did not. For instance, a greater proportion of younger participants and female participants opted to report their demographics in the survey and game, respectively, and samples between both platforms may possibly differ on other unmeasured variables. Future research should use alternative sampling strategies and research designs to mitigate this self-selection bias and collect relevant measures to estimate or control for potential differences between conditions beyond current prior knowledge controls. Fourth, differences in emotions between survey and gamified intervention platforms are suggestive of potential effects of gamification on emotion consistent with past research (Mullins & Sabherwal, 2018), but further experimental research (e.g., randomized control trial) is required before stronger causal claims can be made on the effects of gamified refutations on emotions or learning. Last, several current effects were conventionally small, but as other researchers have noted (Funder & Ozer, 2019; Götz et al., 2022), small effects, particularly those precisely estimated with large field studies (Kraft, 2020; LeBel et al., 2017), may have important cumulative consequences over repeated interactions with a single individual and in interactions across many individuals, which aligns with the potential of gamified interventions to deliver multiple refutations among large samples.

Implications and conclusions

The present study sought to impact public understanding of COVID-19 and advance theoretical knowledge about digital learning contexts and affective processes involved in correcting emotionally laden misconceptions. More recent interventions to correct such misconceptions have revealed the limits of existing methods and theories, which have largely relied on an information deficit model of science communication (Sinatra & Seyranian, 2015; Suldovsky, 2016). In contrast to a deficit model,

the current study represents a new theoretical approach to misconception correction among the public that uses gamification to capitalize on individuals' inherent motivational and emotional strengths. This person-centered approach was intended to augment how individuals affectively interact with challenging educational content, which may overcome limitations of traditional models of science communication that may fail to capture attention or positive engagement. Although more research is needed, we believe that the present study advances our understanding of the emotional and motivational mechanisms involved in correcting challenging misconceptions and how to optimize them with person-centered technological designs, which we hope will ultimately result in more effective educational interventions.

Practically, the integration of two heretofore separate lines of research—belief change and gamification—produced a digital platform with strong potential for future growth. The large, general population sample supports conclusions with relatively strong external validity in the present study and demonstrated potential to support public engagement with science at a broad scale. These advancements can be further built on in future interventions outside of the current pandemic to evaluate generalizability to other contexts and to expand the benefit of refutations for a broader segment of the public across other socioscientific or health topics.

Notes

1. To our knowledge, there is no consensus standard in the field regarding the level of prevalence for a misconception that ought to trigger a corrective intervention. In our internal discussions, we set this level to be 10% of our sample who indicated belief in a misconception since a 10% swing in support for a health policy or collective behavior (e.g., vaccine uptake) is generally meaningful. Below this level (i.e., our sample showing correct responses >90% of the time) we would generally remove a refutation as it may be unintentionally introducing new misinformation to individuals. Over the course of the project, we removed a few refutations for this reason (e.g., claims that garlic, colloidal silver, and vitamin C can treat COVID-19).
2. Differences in data available for analysis exist as a function of individual drop-off or game mechanics described in Methods. Specifically, several questions are only asked when individuals provided incorrect responses and received refutational feedback, including emotional reactions, knowledge retention, and policy support.
3. Standard deviations are higher than means for emotion variables due to the large proportion zeros in the dataset.
4. In response to an anonymous reviewer's question, we explored differences between demographic groups on emotion, retention, and policy support and observed several variations (e.g., Asian and White respondents had higher policy support than Black respondents; female participants had higher policy support than male participants, which in turn had higher policy support than those selecting another gender). However, we opted to not include demographics as another independent variable in the analyses as demographics were not originally integrated into the present theoretical framework or planned analysis. As such, these data were not intended to be used to compare differences between races, ethnicities, ages, or genders in the present study, which we believe warrant a more theoretically informed and comprehensive methodological approach to ensure sound interpretation. Further, the inclusion of age and gender (male or female) as statistical covariates did not change the conclusion of our primary regression analyses.

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