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Testing Communication Strategies to Convey Genomic Concepts Using Virtual Reality Technology

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Abstract

Health professionals need to be able to communicate information about genomic susceptibility in understandable and usable ways, but substantial challenges are involved. We developed four learning modules that varied along two factors: (1) learning mode (*active learning* vs. *didactic learning*) and (2) metaphor (*risk elevator* vs. *bridge*) and tested them using a 2×2 between-subjects, repeated measures design. The study used an innovative virtual reality technology experimental platform; four virtual worlds were designed to convey the concept that genetic and behavioral factors interact to affect common disease risk. The primary outcome was comprehension (recall, transfer). Study participants were 42 undergraduates aged 19–23. The results indicated that the elevator metaphor better supported learning of the concept than the bridge metaphor. Mean transfer score was significantly higher for the elevator metaphor ($p<0.05$). Mean change in recall was significantly higher for didactic learning than active learning ($p<0.05$). However, mean ratings for variables posited to be associated with better learning (e.g., motivation) were generally higher for the active learning worlds. The results suggested that active learning might not always be more effective than didactic learning in increasing comprehension of health information. The findings also indicated that less complex metaphors might convey abstract concepts more effectively.

Communication of Genomic Concepts

Individualized preventive medicine based on genomic risk has been described as an important possible benefit of the Human Genome Project (Collins & McKusick, 2001). According to this paradigm, individuals could learn about their susceptibilities to common diseases and take steps to reduce their risk. In order for individuals to benefit from information about genetic susceptibility, health care providers and public health professionals need to be able to

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communicate the information in an understandable and usable way. However, the challenges involved in such communication are substantial.

Genetic and genomic topics place great information demands on lay individuals (Johnson, Case, Andrews, & Allard, 2005), and individuals' levels of genetic-related knowledge and skills (their "genetic literacy") need to be considered. Although genetic literacy specifically has not been assessed, about 38% of U.S. adults have limited health literacy (Kutner, Greenberg, Jin, Paulsen, & White, 2006), and are likely to have limited genetic literacy as well. Conceptual knowledge is a component of health literacy that has been identified as critical to being able to understand and use health messages (Nielsen-Bohlman, Panzer, & Kindig, eds., 2004), but existing data suggest substantial conceptual knowledge gaps in the area of genetics. For example, while healthy adults may have some familiarity with terms like "genes" or "DNA," they may not understand the underlying concepts (Mesters, Ausems, & De Vries, 2005). Additionally, in the context of genetics, the uncertain, rapidly changing state of scientific knowledge poses difficulty for lay adults, particularly those with limited health literacy (Johnson, Case, Andrews, & Allard, 2005).

The development of communication strategies to increase knowledge of the concept that genetic and environmental factors interact to affect risk of common disease has received recent attention as an important direction for risk communication research (Hernandez, ed., 2005). It will be important for disease prevention initiatives, such as behavior change interventions, to be able to convey to lay individuals that behavioral and environmental factors have large contributions to disease risk, and that behavioral and environmental factors also affect the relationship between genes and health outcomes (Parrott, Silk, Krieger, Harris, & Condit, 2004). Prior research provides limited guidance for the development of effective strategies to communicate such genomic concepts to the general public, however. Existing genetic communication studies have generally focused on genetic counseling or the communication of genetic test results within high-risk families (Green, Biesecker, McInerney, Mauger, & Fost, 2001; Wang, Gonzalez, Milliron, Strecher, & Merajver, 2005). The purpose of this exploratory study was to examine two factors that might inform communication strategies regarding gene-environment interactions targeting lay individuals: (1) learning mode and (2) metaphor selection.

Learning Mode

Both theory and empirical research in knowledge construction and science education suggest that learning mode, or the teaching method by which information is presented to learners, has a crucial influence on increasing conceptual understanding. According to these literatures, the traditional mode of "learning-by-assimilation" (*didactic learning* through listening or reading) might not be optimal for conveying abstract scientific concepts. Dede and colleagues (1997) argued that developing an understanding of such concepts often requires building mental models that incorporate invisible or intangible factors for which learners cannot draw upon real world, personal experiences. In fact, real-life experiences might seem to contradict the way a phenomenon actually works (Fallman, Backman, & Holmlund, 1999). In the context of gene-environment interactions, for example, an interaction might be apparent only at the population level and not within the more limited realm of individuals' personal experiences. "Learning-by-doing" (*active learning*), in which learners are able to construct their own knowledge through self-driven, interactive activities, has been proposed as a better way for learners to master, retain, and generalize new scientific concepts (Dede, Salzman, Loftin, & Ash, 1997; Fallman, Backman, & Holmlund, 1999).

The proposed effects of learning mode on conceptual understanding could occur through different mechanisms, as suggested by Social Cognitive Theory (SCT) and the Elaboration

Likelihood Model (ELM). SCT suggests that self efficacy (i.e., confidence in one's ability to engage in a behavior) might be increased more by active learning, which is similar to mastery learning, than by didactic learning, which is similar to verbal persuasion (Bandura, 1986). The ELM identifies factors that are related to greater systematic processing, and, hence, more stable learning, such as motivation, attention, and involvement (i.e., personal relevance) (Griffin, Dunwoody, & Neuwirth, 1999; Petty & Cacioppo, 1986; Robert & Dennis, 2005). An effect of learning mode upon these variables would increase the plausibility that they might mediate the relationship between learning mode and conceptual understanding. In this exploratory study, therefore, we examined the effects of learning mode on both primary dependent variables of conceptual understanding and a group of secondary dependent variables (e.g., motivation, attention, involvement).

Metaphor Selection

We chose to convey the concept of gene-environment interactions in this study using metaphors, a common educational strategy to teach people about abstract concepts. Metaphors are "a concept from one domain of experience that is used to structure our experience in another domain" (Nordgren, 2003, p. 59). Some metaphors have been developed for genetics to describe the function of DNA (e.g., Advise, 2001; Condit, 1999), but none convey how gene-environment interactions affect common disease risk. Although selection of an appropriate metaphor with which to represent a phenomenon not normally accessible to the human senses is central to effective learning, there are currently no guidelines to direct metaphor development (Winn, 1999). For this study, therefore, we chose two metaphors that might effectively convey the concept of gene-environment interactions to lay individuals. We selected metaphors that (1) would help people visualize risk values resulting from different combinations of risk factors and (2) were based on risk communication research to the extent possible. Because the study used a virtual reality technology platform, we also considered how the metaphors could be operationalized with this technology. The metaphors are described in detail below.

Virtual Reality Technology

We chose to develop and test educational modules using an innovative technological approach to health communication research, virtual reality technology. This technology immerses users in a digital environment such that they can perceive themselves to be in the environment and interacting with it in a psychologically real way. This immersion is realized using a combination of high-resolution graphics software and a carefully designed user interface to create three-dimensional digital environments ("virtual worlds") that users can navigate and explore (Blascovich et al., 2002). In a virtual world, users can control their experiences with naturalistic body movements: walking around, reaching out to 'touch' virtual objects, and interacting with virtual humans. Previous research has shown that users' experiences in virtual worlds can be quite realistic. For example, users often behave similarly toward virtual humans as they do toward real people (Blascovich et al., 2002).

Although virtual reality technology shows great promise for social and behavioral research in genomics (Persky & McBride, in press), it has not been used in genomic communication research to date. However, the technology has proven useful as a laboratory setting for social psychology and educational psychology experiments (Bailenson, Blascovich, Beall, & Loomis, 2003; Moreno & Mayer, 2002). Virtual reality technology provides unique advantages as an experimental platform because virtual worlds can provide high ecological validity without compromising experimental control, thereby increasing the generalizability of findings (Loomis, Blascovich, & Beall, 1999).

For the present study, we explored the effects of learning mode and metaphor on comprehension of the concept of gene-environment interactions in the experimental setting of

a virtual reality technology laboratory. We developed four virtual worlds, an active learning world and a didactic learning world based on each of the two metaphors, to convey this concept. Based on prior literature, we hypothesized that comprehension would be higher for active learning than didactic learning. We also hypothesized that elaboration, motivation, attention, involvement, interest, enjoyment, and believability would be higher for active learning than didactic learning. We did not have an *a priori* hypothesis regarding which metaphor would result in higher comprehension; the comparison of metaphors was an exploratory aim.

Methods

Study Design

In this exploratory study based on a 2×2 between-subjects, repeated measures design, we tested four virtual worlds to investigate which metaphor and which learning mode best conveyed the concept of gene-environment interactions to lay adults. Study participants were randomly assigned to one of four conditions, as described below, completing virtual worlds based on both metaphors and both learning modes.

Sample

We enrolled 42 undergraduates from an existing pool of introductory psychology students. All participants were healthy volunteers aged 18 or older who had not taken a human genetics course in the past five years. Exclusion criteria were: self-reported diagnosis with epilepsy, low vision, hearing problems, being in the third trimester of pregnancy, and vestibular disorders. Participants received $15 for participation.

Description of Virtual Worlds

Educational content—Educational content and language were kept as consistent as possible across all four virtual worlds. All of the worlds were based on a common disease outcome. The worlds were structured around a set of five questions always presented in the same order; participants either determined the answers for themselves (active learning) or were told the answers as part of a lecture (didactic learning). In addition, all worlds had a common set of learning objectives, including: (1) risk of disease varies based on genes; (2) increased genetic risk is not deterministic; (3) risk of disease can be lowered by behavior; and (4) preventive steps are most important for someone with increased genetic risk. The comprehension measures described below were based upon the learning objectives.

We used a hypothetical disease outcome (“gallbladder hyperposia”) for several reasons. We did not want to use a disease for which participants had strong prior misconceptions or emotional reactions. More importantly, a hypothetical disease allowed us to present information about a gene-environment interaction with greater detail than we could for a real disease, based on the current state of science. Gallbladder hyperposia was described as an adult-onset, chronic disease, for which individuals could have one of two levels of genetic risk. Risk of disease was also increased by consumption of foods high in fat, while exercise had a protective effect. In the hypothetical gene-environment interaction, exercise had a greater protective effect for individuals at increased genetic risk for the disease than for individuals at lower genetic risk.

The virtual worlds were designed based on principles developed by Mayer and his colleagues to foster meaningful learning in computer-based multimedia environments (Mayer, Dow, & Mayer, 2003; Mayer, Fennell, Farmer, & Campbell, 2004; Mayer & Jackson, 2005; Moreno & Mayer, 2005). For example, we personalized the content (e.g., “your” rather than “the”), and used a human voice rather than a machine voice. We also incorporated condition-appropriate interactivity into the virtual worlds where possible. The active learning worlds had

game-like interactivity; for didactic learning, participants could request that segments of information be repeated by raising a hand.

Metaphor conditions—The first metaphor developed was a "risk elevator," which was based upon a "risk ladder," a fairly common graphic used to accompany risk communications. Previous research has shown that lay individuals generally understand and can compare different risks presented on a risk ladder (Emmons et al., 1999; Lipkus & Hollands, 1999). As the metaphor was operationalized here, the risk elevator contained rows of buttons representing possible levels of genetic and behavioral risk factors (see Figure 1). Movement of the elevator up or down represented how various combinations of risk factors affected disease risk. When the elevator stopped on a floor, the doors opened and a certain number of virtual people out of 10 standing in the lobby entered a "hyperposia" clinic, another representation of disease risk with a particular risk factor combination. In this metaphor, the interaction between genetic risk and exercise behavior was represented as greater downward movement of the elevator for someone at increased genetic risk than someone at lower genetic risk, reflecting increased protective effects of exercise and greater decrease in disease risk.

A "risk bridge" was selected as the second metaphor, in which disease risk was represented as the proportion of area missing from the bridge and, therefore, likelihood of falling while crossing the bridge. Bridge controls representing the different possible levels of genetic and behavioral risk factors changed the available area of the bridge. Factors that increased risk (e.g., genetic risk factors, consumption of foods high in fat) caused more holes to appear in the bridge or current holes to widen, while protective behaviors (e.g., exercise) caused patches to form over some holes (see Figure 2). With each combination of risk factors, 10 agents attempted to cross the bridge and a certain number fell, representing disease risk. Participants were also able to try and cross the bridge themselves. In this metaphor, the gene-environment interaction was represented as more protective patches forming on the bridge with exercise for someone at increased genetic risk than for someone at lower genetic risk.

The bridge metaphor was distinct from the elevator metaphor on a number of characteristics (e.g., risk conveyed as proportion of an area rather than vertical movement), which allowed us to test conveying the concept in different ways. The bridge metaphor was also more complicated, allowing us to explore whether this greater complexity enhanced learning or distracted from it.

Learning modes—In the two active learning worlds, participants completed a series of self-directed, interactive activities to answer questions posed in the world. For example, in the active learning elevator world, participants could push buttons on the virtual elevator control panel to change levels of genetic and behavioral risk factors (see Figure 1), allowing them to experience the effects of these choices on elevator movement and, therefore, on disease risk. In the active learning bridge world, participants likewise could select combinations of risk factors and observe the effects on disease risk; they were also able to try and cross the virtual bridge themselves.

In the didactic learning worlds, participants listened to a lecture given by a virtual health educator describing how genetic and behavioral factors interact to affect disease risk, using the appropriate metaphor. The same female, multiracial virtual health educator was in both didactic learning worlds. The didactic learning worlds followed the same order of topics as the active learning worlds, and also used screenshots taken from the active learning worlds in order to illustrate learning objectives (see Figure 3). We attempted to model a real-life health education lecture as closely as possible in the didactic learning worlds, as this could be a common way of delivering genomic information in real-world clinical settings in the future.

Study Procedure

Study activities were conducted at the University of California, Santa Barbara's Research Center for Virtual Environments and Behavior. Participants used a head mounted display (HMD)-based system with a Virtual Research V8 HMD. Position was tracked using a WorldViz Precision Position Tracker, and orientation was tracked using an Intersense IS300. The virtual worlds were run on the Vizard VR Toolkit (Version 3.0).

Each participant completed one experimental session of about 90 minutes. Participants were randomly assigned to complete one of the following conditions: (1) active learning elevator world then didactic learning bridge world; (2) didactic learning elevator then active learning bridge; (3) active learning bridge then didactic learning elevator; or (4) didactic learning bridge then active learning elevator. After participants were introduced to the study and did the consent process with a research assistant, they completed a computer-administered pretest questionnaire. Participants then listened to a standard audio introduction to the metaphor used in the virtual world, after which they put on the HMD and had a short warm-up period to get used to the equipment. They then completed the first virtual world, followed by a computer-administered post-test questionnaire. Next, participants completed the second virtual world, followed by the second computer-administered post-test questionnaire. Lastly, participants were debriefed and informed that, although hyperposia is a hypothetical disease, the gene-environment interaction concept applies to other common diseases. The Institutional Review Boards at the National Human Genome Research Institute and the University of California, Santa Barbara approved this study.

Measures

Primary dependent variables—We assessed the primary outcome of comprehension using two different measures, one of recall (11 items) and one of transfer (4 items). Recall items assessed how much presented information participants remembered (e.g., "Exercising will lower someone's chance of getting gallbladder hyperposia"). The same eleven true/false recall items were included in the pretest and both post-test questionnaires; number of correct answers was summed. Change in recall score between post-test and pretest was used in analyses to control for the effect of guessing. The transfer measure assessed whether participants could apply information from the virtual world to new disease contexts. For example, one item asked participants to apply what they had learned about the effect of exercise on hyperposia risk to the context of heart disease (i.e., "Exercising will lower the chance of getting heart disease more for someone who has a risk version of a gene for heart disease than someone who does not have a risk version of that gene.") Because participants were directed to answer the four true/false transfer items based on information they had learned, transfer was assessed only in the post-test questionnaires using the same items in each. Number of items answered correctly was summed.

Secondary dependent variables—These variables were assessed at the first post-test only, based upon the first virtual world that respondents completed.

Elaboration was assessed based on the approach described in Eveland et al. (2003) using three items (e.g., "I found myself thinking about the information in the virtual environment") answered on seven-point response scales. Scores on these items were averaged; Cronbach's alpha value (α) was 0.57.

Motivation and attention were assessed with single items with seven-point response scales based on the approach of Moreno & Mayer (2005) (i.e., "If you had a chance to use a program like this again, how eager would you be to do so"; "How much attention did you pay to the information in the virtual environment").

Involvement items were based on Roser (1990) and Cheng (2005). The three items (e.g., "Is information about how genes affect disease risk important to you") were answered on three-point response scales and averaged (α=0.74).

Interest and perceived difficulty were each assessed using two seven-point Likert scale items (e.g., "How interesting was this information"; "How difficult was the information") based on the approach of Moreno & Mayer (2005). Scores on each pair of items were averaged; α=0.83 for interest and α=0.53 for perceived difficulty.

Enjoyment of the virtual world was measured using three seven-point Likert scale items from Swinth & Blascovich (2001) (e.g., "I would have liked the experience to continue."). Scores on these items were averaged (α=0.89).

Presence (i.e., participants' sense of immersion in the virtual world) was assessed using eight seven-point Likert scale items adapted from Swinth & Blascovich (2001). Scores on the items (e.g., "I wanted to reach out and touch things in the virtual environment") were averaged (α=0.93).

We also asked participants to rate how much they liked the virtual world overall and its believability on seven-point Likert scales. In addition, we included open-ended questions asking participants what they liked and disliked about the virtual worlds.

In order to assess participants' sociodemographic characteristics, we collected participant age, race/ethnicity, parental educational attainment, and whether they had friends or family members who had been diagnosed with gallbladder problems or a genetic disease.

Analysis

Data were analyzed using SAS Version 8 for Windows (Cary, NC). Descriptive statistics were examined for all variables. We used one-way ANOVA tests to examine differences in recall and transfer by learning mode and by metaphor. In addition, we used one-way ANOVA tests to examine differences in the secondary dependent variables by learning mode; we were not able to formally test mediation by these variables due to the small sample size. Also, because of the sample size in this exploratory study, we report the mean scores of compared groups as well as the significance of the associations. Statistical significance was assessed as $p<0.05$.

Results

Participants ranged in age from 19–23 (see Table 1). About two-thirds (69%) were female. Half (50%) described themselves as white, and 31% as Hispanic. Parental education varied substantially across participants. Only 5% had a friend or family member who had been diagnosed with gallbladder problems, but about one-third (36%) reported having a friend or family member who had been diagnosed with a genetic disease.

Change in recall score from baseline to the first post-test was highest in the condition that completed the didactic learning elevator world first (mean [M]=3.4, standard deviation [SD] =2.7), followed by those who completed the didactic learning bridge world (M=2.3, SD=2.3) and then the active learning worlds (see Table 2). When the didactic learning conditions and active learning conditions were combined, mean change in recall score after the first virtual world was significantly higher for didactic learning than active learning [$F(1,40)=4.49$, $p=0.04$]. We did not observe additional improvements in recall after the second virtual world, with the exception of participants who completed the didactic learning elevator as their second world (M=0.7, SD=1.3). Transfer score after completion of the first virtual world was highest for the didactic learning elevator (M=2.5, SD=1.0), followed by the active learning elevator

(M=2.1, SD=0.3) and then the two bridge metaphor worlds. When the metaphor conditions were combined, mean transfer score was significantly higher for the elevator metaphor than the bridge metaphor [$F(1,40)=4.57$, $p=0.04$]. As with recall, transfer scores did not generally improve after the second virtual world.

Mean scores on the secondary dependent variables after completion of the first virtual world were generally higher for the elevator metaphor worlds, although these differences were not significant (see Table 3). More specifically, motivation rating was higher for the active learning elevator world (M=5.6, SD=1.1) than for the other worlds. Attention rating was also higher for the elevator metaphor worlds than the bridge metaphor worlds, with the highest rating for the active learning elevator world (M=6.1, SD=0.7). Reported interest was also highest for the active learning elevator world (M=5.0, SD=1.5), as was presence (M=5.0, SD=1.2) and enjoyment of the virtual world (M=5.4, SD=0.8). Participants liked the active learning elevator world (M=5.7, SD=1.3) and didactic learning elevator world (M=5.1, SD=1.9) more than the active learning or didactic learning bridge worlds (M=4.6, SD=1.8 and M=4.4, SD=1.4, respectively). Although participants generally found all four worlds believable, this rating was highest for the active learning elevator world (M=5.8, SD=0.8).

Perceived difficulty was low for all four worlds, but the bridge metaphor worlds were rated as more difficult than the elevator metaphor worlds (highest rating for active learning bridge M=2.4, SD=0.8), although this difference was not significant. Reported elaboration was also somewhat higher for the bridge metaphor worlds than the elevator metaphor worlds. Involvement scores were similar across all four worlds. After completing two worlds, 57% of participants preferred the elevator metaphor and 43% the bridge metaphor (data not shown).

Discussion

The purpose of this study was to explore the effects of learning mode and metaphor on comprehension of a genomic concept using a virtual reality platform. We developed and tested four virtual worlds designed to convey to lay audiences the concept that gene-environment interactions affect common disease risk. We selected two metaphors, a risk elevator and a bridge, and developed both an active learning and didactic learning virtual world for each metaphor. The results indicated that the elevator metaphor better conveyed the genomic concept of interest to participants than the bridge metaphor. Both measures of comprehension (recall and transfer) were higher for the elevator metaphor worlds, and this difference was significant for mean transfer score. In addition, most of the variables we examined due to their theoretical relationship with more effective learning (e.g., elaboration, attention, motivation) had higher mean ratings for the elevator metaphor than the bridge metaphor worlds, although these differences were not significant. More participants preferred the elevator metaphor than the bridge metaphor.

We decided to empirically test different metaphors because there is little guidance in the literature to direct metaphor design for abstract scientific concepts (Winn, 1999). The metaphors tested here differed on a number of dimensions. The risk elevator was a simpler, more straightforward metaphor based on a common health communication graphic. We propose that this metaphor might be more consistent with how lay individuals conceptualize changes in risk (i.e., increase in risk is reflected by upward movement of elevator) or with other risk visuals they might have seen, leading to greater improvement in comprehension. The bridge was a more complex metaphor. The finding that elaboration ratings were somewhat higher for the bridge metaphor than the elevator metaphor worlds suggests that participants were thinking somewhat more deeply about the bridge metaphor. The many pieces of the bridge metaphor to which participants could attend may have distracted from learning of the overall concept, however, as also suggested by the somewhat higher difficulty ratings for the bridge

metaphor worlds. This metaphor, with its horizontal rather than vertical orientation, might also have been inconsistent with how lay individuals conceptualize changes in risk. These findings therefore suggest that less complex metaphors that are consistent with how lay individuals conceptualize abstract concepts might convey these ideas more effectively. Next steps for this line of research could include comparing other metaphors that are grounded in risk communication theory to investigate systematically characteristics that affect learning and using formative research to better map tested metaphors onto how lay individuals conceptualize the concept of disease risk.

Another intriguing study finding was that comprehension was significantly higher for didactic learning than active learning. Previous research had generally suggested that active learning would better improve comprehension (e.g., Dede, Salzman, Loftin, & Ash, 1997). Some educational research, however, has not supported the superiority of active learning compared to didactic learning (Sigler & Saam, 2007). Our findings provide some support to the proposition that while active learning might be better for application, didactic learning might be better for increasing knowledge (Ormrod, 2005; Sigler & Saam, 2007). The better learning we observed with the didactic approach might also be an effect of the undergraduate population who participated in the study, since they are in a university setting that is heavily lecture-based. Future research is needed to examine the effects of learning mode on comprehension in community-based samples.

We also observed that for most of the variables theoretically related to more effective learning, ratings for the active learning worlds were higher than for the didactic learning worlds. This finding is consistent with prior research showing that students felt they learned more from active learning approaches (de Caprariis, Barman, & Magee, 2001). Additional research with larger samples is needed, however, to test formally possible mechanisms mediating the association between learning mode and comprehension. Future studies based on other virtual worlds could also explore the effect of learning mode on educational approaches designed to teach skills (e.g., using disease risk numbers) rather than to increase conceptual knowledge. It may be the case, for example, that active learning is more effective for skill building than didactic learning through mechanisms suggested by the SCT, such as increasing self efficacy.

The limitations of this study should be considered in interpreting the results. We had a small sample size for this exploratory study, which limited our power to examine the statistical significance of observed differences. As mentioned above, all participants were undergraduate students, which may have had an effect on learning outcomes. Participants might also have had greater familiarity with interactive gaming and use of technology for learning, although this possibility was not supported by the finding of greater effectiveness of didactic learning. The measures were self-reported, and therefore subjective. Reliability was less than optimal for our measures of elaboration and perceived difficulty, although an examination of ratings for the individual items from these measures did not change the interpretation. Involvement items had only three-point response scales, which might have limited our ability to detect changes in this construct. Further measures development will be important for this line of research, including developing objective measures for constructs such as attention and elaboration and, perhaps, using measures for the secondary dependent variables with more items. Additional research will also be needed to determine whether the effects observed here using virtual reality technology as an experimental platform will also hold true for real-world educational approaches that are more disseminable.

Despite these limitations, the results indicated that the elevator metaphor better supported learning of the gene-environment interaction concept than the bridge metaphor. These findings suggest that message designers should select less complex metaphors that are consistent with how the target audience conceptualizes an abstract concept. The results also indicate that active

learning might not be more effective than didactic learning in some health education contexts, highlighting the importance of pre-testing educational strategies. Future research should examine which of these variables (learning mode or metaphor) is more important in increasing comprehension, or whether these variables interact in their effects.

In conclusion, limited genetic conceptual knowledge is likely to interfere with individuals' understanding of messages about genetic risk, and limited guidance exists for the development of strategies to educate the lay public about genomic concepts. Future research can build upon these results to gain a better understanding of which learning mode is most effective in conveying information about abstract, genomic concepts to different populations, as well as the mechanisms by which this learning occurs. Development and evaluation of effective strategies to improve genetic literacy is critical in order to translate research advances in genomics into improvements in public health.

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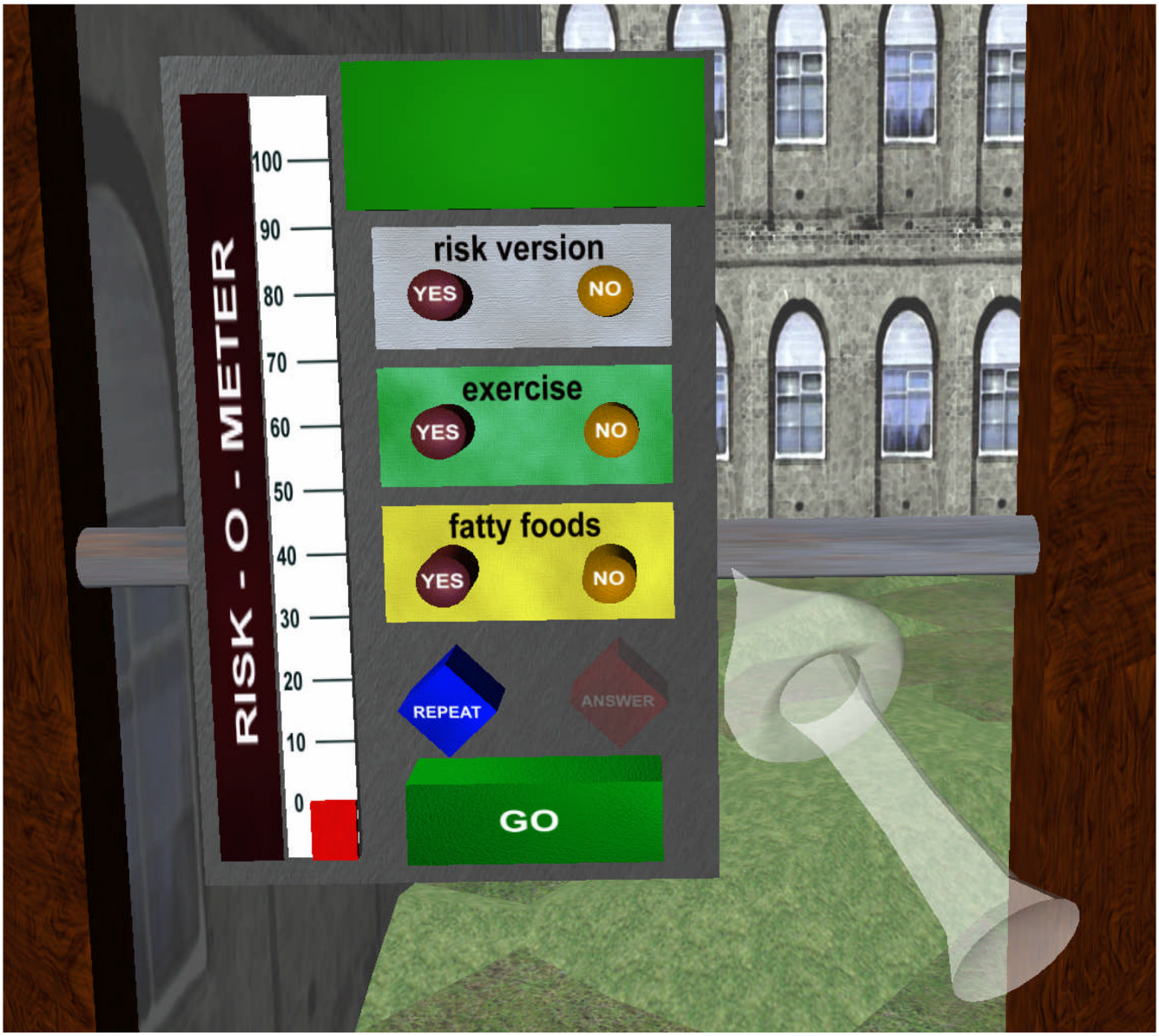

Figure 1.
Screenshot from active learning elevator metaphor virtual world showing control panel.

Figure 2.
Screenshot from active learning bridge metaphor virtual world.

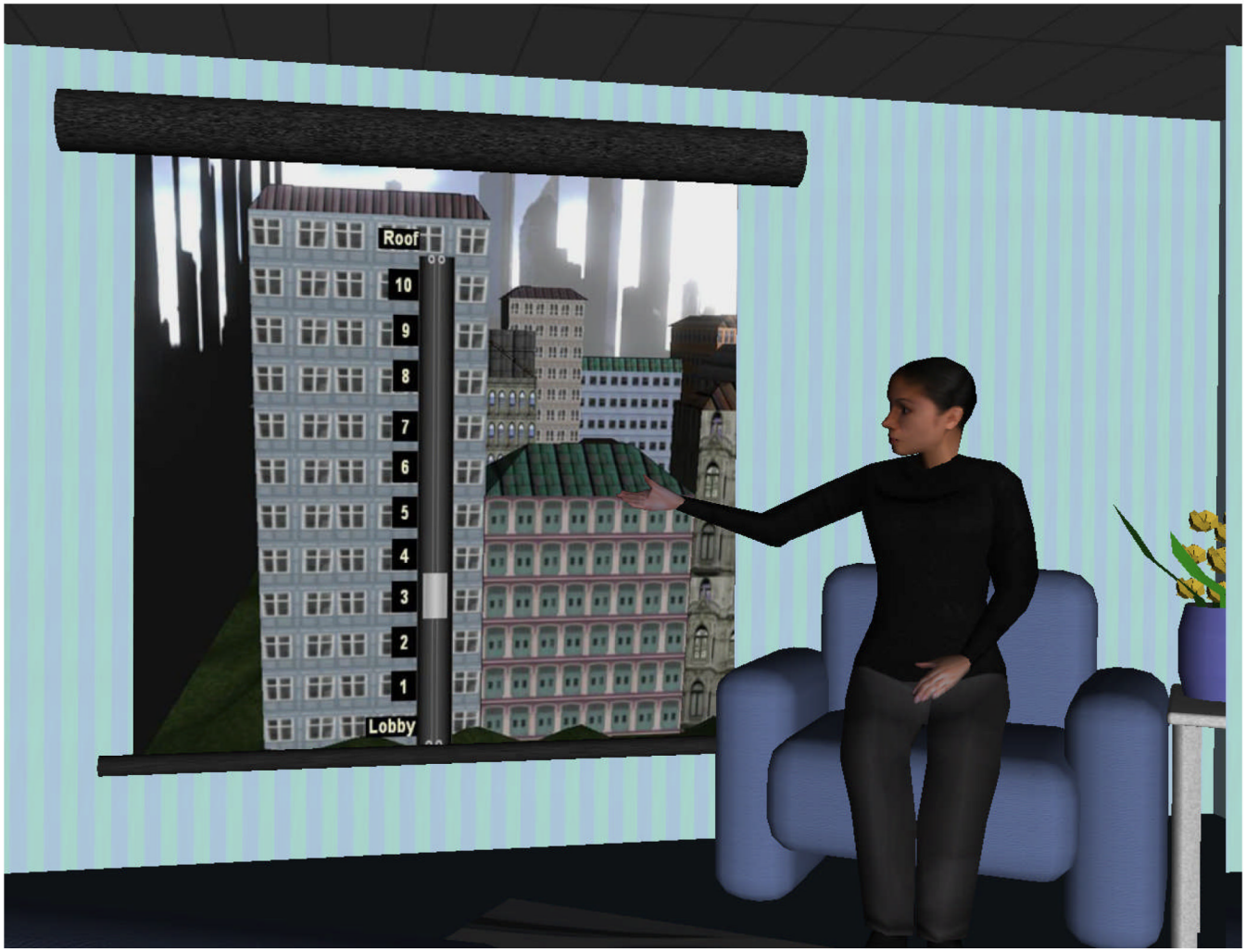

Figure 3.
Screenshot from didactic learning elevator metaphor world with virtual health educator.

Table 1

Characteristics of participants (n=42).

Characteristic	N (%)[a]
Age	
19	17 (40%)
20	12 (29%)
21	7 (17%)
22	4 (10%)
23	2 (5%)
Gender	
Female	29 (69%)
Male	13 (31%)
Race/ethnicity	
White	21 (50%)
Hispanic	14 (31%)
Asian/Asian American	3 (7%)
Native Hawaiian/Pacific Islander	1 (2%)
Other	3 (7%)
Mother's education	
Less than high school	4 (10%)
High school graduate	6 (14%)
Some college	11 (26%)
College graduate	11 (26%)
Post graduate degree	10 (24%)
Father's education	
Less than high school	5 (12%)
High school graduate	7 (17%)
Some college	3 (7%)
College graduate	13 (31%)
Post graduate degree	14 (33%)
Family member or friend diagnosed with gallbladder problem	
Yes	2 (5%)
No/Don't know	40 (95%)
Family member or friend diagnosed with genetic disease	
Yes	15 (36%)
No/Don't know	27 (64%)

[a] Percentage values may not total 100% due to rounding.

Table 2

Comprehension (recall and transfer) scores across experimental conditions.

Condition	Change in recall between pre-test and post-test 1 Mean (SD)	Change in recall between post-test 1 and post-test 2 Mean (SD)	Transfer score at post-test 1 Mean (SD)	Transfer score at post-test 2 Mean (SD)
Active elevator/ Didactic bridge (n=10)	1.7 (1.4)	−0.5 (1.3)	2.1 (0.3)	1.9 (0.6)
Didactic elevator/ Active bridge (n=10)	3.4 (2.7)	−0.4 (0.8)	2.5 (1.0)	2.5 (1.0)
Active bridge/ Didactic elevator (n=10)	1.3 (1.2)	0.7 (1.3)	1.8 (0.4)	2.0 (0.7)
Didactic bridge/ Active elevator (n=12)	2.3 (2.3)	−0.6 (1.6)	2.0 (0.4)	2.1 (0.5)

SD = standard deviation

Table 3

Ratings for secondary dependent variables after completion of first virtual world.

Variable	Active elevator (n=10) Mean (SD)	Didactic elevator (n=10) Mean (SD)	Active bridge (n=10) Mean (SD)	Didactic bridge (n=12) Mean (SD)
Elaboration	4.7 (1.0)	4.6 (1.1)	5.0 (0.7)	5.0 (1.1)
Motivation	5.6 (1.1)	5.1 (2.0)	4.8 (1.3)	4.8 (1.5)
Attention	6.1 (0.7)	5.6 (1.6)	4.9 (1.2)	5.4 (1.2)
Involvement	2.5 (0.4)	2.7 (0.4)	2.6 (0.5)	2.6 (0.4)
Interest	5.0 (1.5)	4.2 (1.8)	4.7 (1.0)	4.5 (1.3)
Perceived difficulty	2.0 (0.9)	1.7 (0.5)	2.4 (0.8)	2.2 (0.9)
Enjoyment of the world	5.4 (0.8)	4.5 (1.6)	4.4 (1.5)	4.4 (0.9)
Presence	5.0 (1.2)	3.9 (1.9)	4.5 (1.5)	4.2 (1.5)
Liked world	5.7 (1.3)	5.1 (1.9)	4.6 (1.8)	4.4 (1.4)
Believability	5.8 (0.8)	5.4 (1.6)	5.6 (1.3)	5.3 (1.7)

SD = standard deviation