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RESEARCH REPORT

Drugs and the Brain: Learning the impact of methamphetamine abuse on the brain through a virtual brain exhibit in the museum

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Drugs and the Brain: A Serious Game, a prototype museum exhibit, was designed to employ virtual models of the brain into a video game format. It was done to create a fun and engaging way of conveying knowledge and concepts about neuroscience, as well as the impact of methamphetamine abuse on the brain. The purpose of this study is to evaluate this prototype exhibit that promises to educate participants from various age, ethnicity, and gender backgrounds, and to establish a stronger concept of drug abuse prevention among children. A quantitative methodology using the pre- and post-experimental designs was conducted on 175 museum visitors. A series of two-sample paired *t*-tests and subsequent ANOVAs were performed to examine the difference between pre- and post-tests and to determine if there was a difference in the results in age, gender, ethnicity, and race. Results showed that both the understanding and attitudes of the participants toward the impact of methamphetamine abuse on the brain improved significantly ($p < 0.01$).

Keywords: *Informal education; Museum; Public; Science education; Evaluation; Serious game; Drug use education*

Introduction

Today, video games have an incredible fan following, consisting of people of all ages. Today's youth are extremely game-literate, proving incredibly adept at developing skills that allow them to connect and manipulate information in the virtual world of video games to those in the real world. Many researchers have suggested that video games have the potential to make a positive impact on education (Annetta, Murray,

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Gull-Laird, Bohr, & Park, 2006; Dede, 2005; Gee, 2003a, 2003b; Jenkins, 2006; Prensky, 2001; Squire, 2003). As the awareness of the educational uses of video games increases, National Institute on Drug Abuse (NIDA) initiated the solicitation for the *Development of a Virtual Reality Environment for Teaching about the Impact of Drug Abuse on the Brain* (NIDA, 2006). In response to the solicitation that 'seeks the development of a virtual reality environment that can be used in educational settings to teach about how drugs of abuse (both illicit and licit) affect the brain and behavior' (p. 3), a touring museum exhibit named *Drugs and the Brain: A Serious Game* was developed.[1] This exhibit was designed to employ detailed, 3D graphical models of the brain combined with a video game as a fun and engaging way to convey basic concepts of neuroscience, as well as the neurotoxic and long-term effects of methamphetamine abuse on the brain. NIDA's objective is to let all members of the society understand the role of science, biology, and technology, and their relationship to neuroscience, behavioral science, and drug abuse and addiction research. Thus, the exhibit is aimed at improving the neuroscience literacy of the general public and establishing a stronger concept of drug abuse prevention among children.

The goal of the study is to test and evaluate this prototype exhibit that promises to teach participants from various ages, ethnicities, and gender backgrounds the neurobiologically based impact of methamphetamine abuse on the brain. One hundred and seventy-five museum visitors were recruited to view the prototype and complete instruments that assessed their knowledge gain and attitude changes toward the impact of methamphetamine abuse on the brain. Focusing on differences among age, gender, ethnicity, and race groups, the evaluation investigated the following research questions:

(1) Do participants gain knowledge of neuroscience and the impact of methamphetamine abuse on the brain after the exhibit?
(2) Does the exhibit improve participants' attitudes toward the impact of methamphetamine abuse on the brain?
(3) Does sensation seeking affect the understanding and attitudes toward the impact of methamphetamine abuse on the brain?

Hypotheses

It was hypothesized that an effective, virtual reality learning environment with a video game, which provides the latest findings in neuroscience research to teach the impact of methamphetamine abuse on the brain, may be of substantial benefit in enhancing the neuroscience literacy of the public and improving their negative attitudes toward methamphetamine use.

Literature Review

Drug Use Education and Neuroscience Literacy

Drug abuse remains a major public health problem in America. The findings from brain image research indicate that drug abuse induces abnormal neurotransmitter release and severe and persistent brain damage, which subsequently lead to motor and cognition impairments (Bowyer & Ali, 2006; Sim et al., 2007; Simon et al., 2000; Thompson et al., 2004; Volkow et al., 2001). Drug use results in severely negative consequences, yet people generally lack the knowledge about the impact of illicit or licit drugs on the brain.

Most of the current drug abuse prevention programs focus on life skills training, and these skills could be classified into two categories: (1) the resistance skills, for rejecting social influence and misconceptions of drug use; and (2) the generalized skills, for coping with social competency and stressful life situations (Ellickson, 1995; Marsch, Bickel, & Badger, 2007). However, those programs which teach people the consequences of drug abuse from a neuroscience perspective are few. Moreover, neuroscience topics are usually not in school science curricula.

'Neuroscience Literacy' could be defined as:

> the knowledge and understanding of concepts and processes in neuroscience required to understanding issues related to diseases and disorders of the brain, as well as how humans interact with their environment and each other because of their unique nervous system characteristics. (Zardetto-Smith, Mu, Phelps, Houtz, & Royeen, 2002, p. 397)

In short, it refers to public understanding of concepts and/or knowledge in neuroscience, which is important for individuals to better understand themselves and make informed decisions about health and drug abuse in their daily lives. With the increase in the awareness of the importance of neuroscience literacy, neuroscience professionals have started programs to help both children and adults learn about the nervous system (Fox, 2007; Zardetto-Smith, Mu, Carruth, & Frantz, 2006; Zardetto-Smith et al., 2002). NIDA specially provides grants to fund projects that aim at teaching the public the impact of drug abuse on the brain (NIDA, 2006).

Virtual Reality and Serious Games

'Virtual Reality' is defined as an electronic-generated environment. This environment is filled with computer-generated graphics, enabling users to see in a 2D or 3D visual display apparatus or stereo-viewing goggles, and to interact with it with the aid of some sort of input device like mouse, joystick, or reality gloves (Steuer, 1992). Using virtual reality to simulate the real-world environment provides users a unique immersive experience, allowing new possibilities for experimentation, operation, manipulation, and exploration that are impossible or impractical (Johns Hopkins University Applied Physics Laboratory, n.d.). Virtual reality is an emerging technology that has already been in use effectively for a number of years for various purposes, such as medical and surgical education (Sarker & Patel, 2007; Ward, Charissis, Rowley, Anderson, & Brady, 2008), business and industry training (Sawhney, Mund, & Koczenasz, 2001), and the treatment of phobias and pain control (Hoffman et al., 2008; Reger & Gahm, 2008). Especially, since neuroscience includes a number of models of the brain and the skull, virtual reality models that provide an extra dimension than 2D images are more informative for both the quality of visual information and utility of surface visualization (Kelley et al., 2007).

'Serious Games' is a movement that started in 2002, and aims at applying video games and simulations outside of entertainment to play roles in areas such as teaching and learning (Annetta & Cheng, 2008; Gudmundsen, 2006). Nowadays, serious game has become a general term that refers to using video games and/or simulations for educational purposes. Here, video game refers broadly to an electronic or computerized game played by manipulating images on a video display or television screen; and simulation is defined as a representation of real life that accurately demonstrates a physical or simulated processes or phenomenon.

Why do researchers use video games/simulations for educational purposes? A comprehensive survey of the research in the past century supports the use of games and play in learning and cognitive development. In his book *Mind in society: The development of higher psychological processes*, Vygotsky writes, 'The influence of play on a child's development is enormous' (1978, p. 96). He believes play is important to the social and emotional development of children, as well as their cognitive development. 'Play can be thought of as a scaffolding activity that has the potential to engage children in issues and debates that are not addressed directly through participation in society and through exposure to curriculum of schools' (Lim, Nonis, & Hedberg, 2006, p. 212). Games and play include many varieties and settings, and video game play is one that has grown at an astronomical pace over the past two decades.

The effect of video game play in learning and cognitive development is also supported by Piaget's theory (Holmes & Honeycutt, 2008). Van Eck (2006) argues that video games that promote curiosity and challenge player's abilities facilitate the process of what Piaget called cognitive disequilibrium and resolution. He, therefore, states that video games thrive as teaching and learning tools when they create a continuous cycle of cognitive disequilibrium and resolution while also allowing the players to be successful.

Besides, video games/simulations motivate participants because the learning process is fun and helps individuals 'learn through doing' (Annetta & Cheng, 2008; Kirriemuir & McFarlane, 2004). Playing video games not only improves cognitive growth, but also supports valuable skill development, such as strategic thinking and planning, communication and negotiating skills, group decision-making, data-handling, and visual-spatial thinking. Moreover, an experiment by Griffith, Voloschin, Gibb, and Bailey (1983) concludes that the players of video games have better performance on visual and motor coordination than non-players in the same peer group.

Oblinger (2006) argues that video games carry enormous potentials in engaging students in abstract thinking and passing on of valuable information, skills, attitudes, and ways of thought, which in the past were taught by teachers in classrooms. Gee (2003a, para. 2) also states, 'when kids play video games they experience a much more powerful form of learning than when they are in the classroom. Learning isn't about memorizing isolated facts. It's about connecting and manipulating them'. Gee's statement can be seen as an indicator on the potential impact video games have on learning, and shows an increased interest by educators to develop this field to assist the learning process.

Video games can also provide people with flow experience (Csikszentmihalyi, 1990) which individuals enjoy. Research supports the use of video games as teaching tools to enhance learners' enjoyment and engagement as well as to motivate students to learn new things (Rosas et al., 2003; Shreve, 2005). Many studies have also indicated that integrating video games into science classrooms improves students' ability to learn science concepts and increases performance (Annetta, Mangrum, Holmes, Collazo, & Cheng, 2009; Squire, Narnett, Grant, & Higginbotham, 2004); however, there seems to be a lack of research that investigates the role of serious games in informal learning settings.

Interactive Science Exhibit

Rennie and McClafferty (1996) define interactive exhibits as 'those which respond to action from the visitor and also invite a further response; there is a dependency between the visitor and the exhibit' (p. 58). Rennie and McClafferty (1996) review several studies which have focused on interactive science exhibits and science education, arguing that interactive science exhibits including play and experimentation are the key components of a successful learning for visitors of all ages. In short, a very important factor of a successful exhibit is that it should contain two conditions, 'visitors had to enjoy themselves and they had to learn something' (Perry, 1989, as cited in Rennie & McClafferty, 1996).

With advances in computer technologies and networked learning, educators and researchers are beginning to create our next generation of blending learning environments that are highly interactive, authentic, meaningful, learner-centered, and fun (Kirkley & Kirkley, 2004). Since video games/simulations provide people with a flow experience that is enjoyable and engages players in the learning activities embodied and facilitates learning and cognitive development, employing a 3D virtual brain tour combined with a video game format as a teaching and learning tool has potential to be an interactive science exhibit for improving the neuroscience literacy of visitors of all ages.

Sensation Seeking

According to Zuckerman, the general definition of sensation seeking is a biologically based personality trait that is 'the need for varied, novel, and complex sensations and experiences and the willingness to take physical and social risks for the sake of such experience' (Zuckerman, 1979, p. 10). It has been evidenced by a substantial body of studies that sensation seeking is significantly associated with addiction behaviors such as alcoholism and drug abuse (Donohew et al., 1999; Martin et al., 2004; Sarramon, Verdoux, Schmitt, & Bourgeois, 1999). In other words, high-sensation seekers generally tend to have a higher possibility and an earlier onset of use of a variety of drugs than low-sensation seekers (D'Silva, Harrington, Palmgreen, Donohew, & Lorch, 2001).

Two explanations are generally believed to underlie the relationship between sensation seeking and alcohol and drug use (Segal, Huba, & Singer, 1980). One reason is that the risk and illegality of pursuing alcohol or drug use provides sensation seekers with a source to find stimulation, and the other is that sensation seeking could directly activate the neurological mechanism that is induced by alcohol and drugs themselves (Bardo, Donohew, & Harrington, 1996). It is assumed that novel activities might provide high-sensation seekers with an alternative source of stimulation and/or neurologically rewarding effects similar to those provided by drug use; hence, the continuing studies subsequently suggest that in addition to a prevention strategy for most individuals, an alternative approach that targets high-sensation-seeking groups might need to be developed for meeting their needs for sensation and thus for contributing to reducing the risk of using drugs (Arria, Caldeira, Vincent, O'Grady, & Wish, 2008; D'Silva et al., 2001).

Since 3D simulations and video games are typically seen as novel activities for most people, employing them as an interactive exhibit in a museum setting to disseminate information of the impact of drug use might increase the possibility of meeting the needs of high-sensation seekers for sensation and further to provide them with an access to knowing the consequences of drug use. Therefore, the other purpose for the present study was also hoped to be that by using the virtual interactive exhibit, the possibility of attracting and holding the attention of high-sensation-seeking individuals could be increased, which subsequently would improve their understanding and attitudes toward the impact of drug abuse on the brain, and ultimately change their behaviors.

Methods

Science Content

Comparing with control subjects, methamphetamine-dependent individuals performed significantly worse on executive functions (Chang et al., 2002; Kalechstein, Newton, & Green, 2003). Executive function is defined as 'a set of cognitive abilities that control and regulate other abilities and behaviors' (Barry, n.d.). One of the typical executive functions is the ability to intentionally stop or prevent actions that are already underway, which is called response inhibition. Research indicates that methamphetamine-dependent users have deficits in their ability to inhibit responses, causing reduced cognitive inhibition (Salo et al., 2002). Such deficits in response inhibition are typically associated with permanent impairments of right-lateralized inferior frontal gyrus (IFG) (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Rubia et al., 2001). Hence, the causal relationship is that methamphetamine causes persistent damages of IFG, which subsequently impairs response inhibition.

These deficits of inhibitory abilities bring inconveniences to our daily lives, and sometimes may lead to severe damages. For instance, the delayed stop-signal inhibition (delayed reaction time) which individuals perform to do a no-go (stop) response may influence driving skills, causing severe accidents. Thus, the important goals for an intervention on neuroscience literacy and public understanding of drug effects need to build upon: (1) the basic knowledge of concepts and processes in neuroscience among the public; (2) the general awareness of physical and functional impairments associated with taking drugs; and (3) the essential understanding of negative consequences resulting from drug use in our daily lives.

Exhibit Design

A prototype that features a single drug, methamphetamine, was therefore developed. It employs 3D models of a functioning brain and a video game to virtually visualize and display the aforementioned consequences to the pubic, and four objectives were intended to be met:

(1) to identify the basic brain structures and their functions,
(2) to learn how the brain produces go and no-go signals,
(3) to examine the physical and functional impairments associated with taking methamphetamines based on the latest research, and
(4) to recognize the negative consequences of taking methamphetamines in our daily lives.

The prototype exhibit consists of two parts and takes participants 10–15 minutes to interact with. A 3D virtual brain tour, viewing and manipulating the comparison between a normal brain and a methamphetamine-impaired brain, is presented first. Then, a driving video game simulating driving skills under methamphetamine-abused conditions is given. The models of the brain were presented on autostereoscopic 3D displays, which provides the same 'virtual reality' as 'VR goggles', but without the need to wear a headset, and were viewable on the same monitor by multiple people simultaneously. With a videogame controller, participants could then navigate and manipulate the virtual brain, authoring their own learning experience (Figure 1).

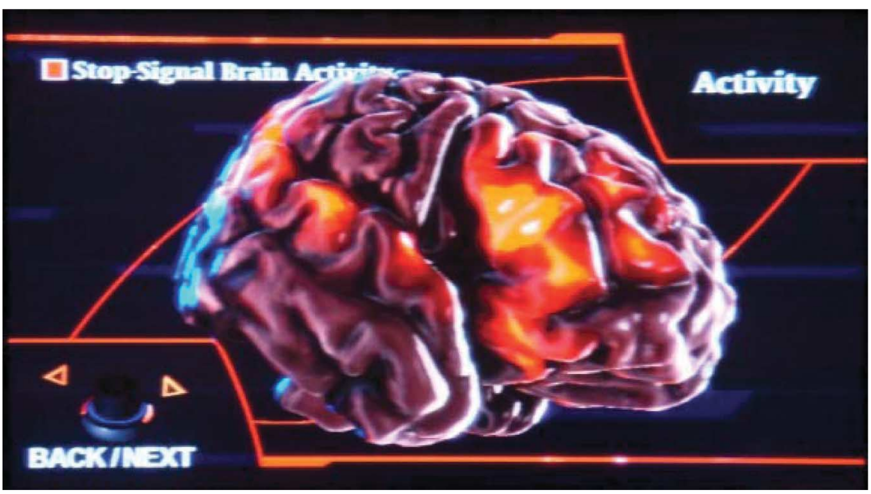

Figure 1. Screenshot showing the 3D effects of the brain

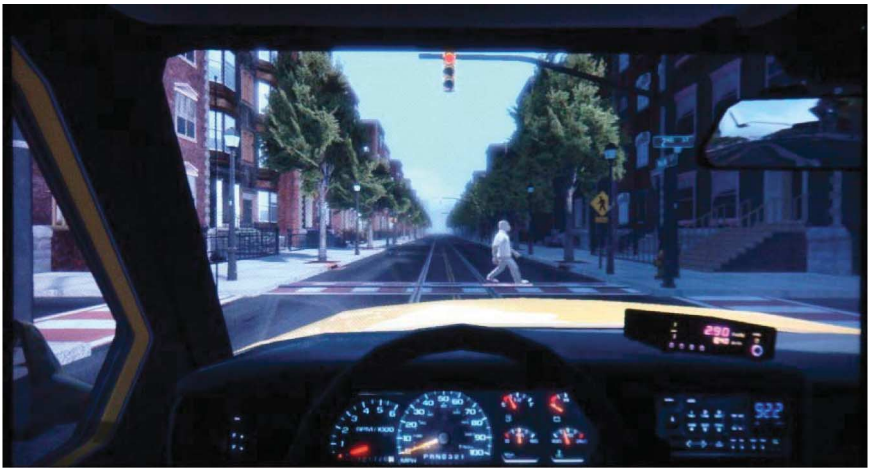

Figure 2. Screenshot showing the driving game that simulates methamphetamine-abused conditions

For the driving video game that simulates methamphetamine-abused conditions, since methamphetamine abusers have deficits in response inhibition, it would be difficult for them to produce a no-go response in time. In the game environment, once the players speed across the street when the light turns red, they have a delayed reaction time to stop, causing them to hit cars or pedestrians, creating accidents (Figure 2).

Setting of the Study

This study was set on the second floor of the North Carolina Museum of Life and Science in Durham, NC. Posters were created and placed at the entrance to the museum, and the top of the stairs on the second floor to attract participants to the virtual brain exhibit area. The room chosen for this exhibit was a separate room from the rest of the museum, used for classes and sensitive exhibits. It served as a quiet and safe area to perform this study. Finally, the exhibit was tested for usability on the first weekend and the study of its effectiveness (i.e., its feasibility) was conducted on the second weekend when the exhibit was available to the general population.

Participants

A total of 175 people with an age range from 6 to 82 participated in the study. Of these, 90 (51.43%) were males and 85 (48.57%) were females. According to age, the participants were categorized into three groups, adults (age 18+), youths (age 13–17), and children (age 6–12). There were 65 (37.14%) adults, 9 (5.14%) youths, and 101 (57.71%) children. Besides, because the US funding agencies are interested in the impact of programs on underrepresented audiences and because of the ethical considerations requested by the institutional review board, both race and ethnicity that describe the socio-cultural construct of the US society were collected (National Institutes of Health, 2001). Ethnicity was categorized as Hispanic/Latino or not Hispanic/Latino. Seven (4%) were Hispanic/Latinos and 168 (96%) were not. Moreover, racial profiles were also accounted for. Respectively, there were 11 (6.29%) Asians, 19 (10.86%) Black/African-Americans, and 145 (82.86%) Caucasians.

Data Collection and Research Design

The study employed the quantitative methodology using the pre- and post-experimental designs. Data were collected through paper-and-pencil survey instrumentation that normally took participants 15 minutes to complete. The instruments consisted of a pre-test and a post-test to examine participants' knowledge gain and attitude change: (1) Pre-test and post-test knowledge instruments consisted of six multiple-choice items that were consistent with the content embedded in the virtual brain exhibit; and (2) the pre-test and post-test attitude surveys contained three questions that examined participants' attitudes toward the impact of methamphetamine abuse on the brain. Cronbach's alpha was 0.76 for the knowledge test and 0.71 for the attitude survey. Both survey questionnaires were created and validated by neuroscientists who contributed ideas for developing the virtual interactive exhibit. In particular, face validity was ensured by peer reviews and participant feedback from a pilot study. Moreover, a sensation-seeking survey, which included four questions that were designed to ascertain possible alignment between sensation-seeking personality and understanding of the impact of methamphetamine on the brain, was distributed before the exhibit. The sensation-seeking survey was adopted from the Brief Sensation Seeking Scale (BSSS; Hoyle, Stephenson, Palmgreen, Lorch, & Donohew, 2002). It is originally an assessment including eight items; four items were additionally taken out for simplifying it to become a survey involving four items (BSSS-4; Stephenson, Hoyle, Palmgreen, & Slater, 2003). Cronbach's alpha was 0.65 for the four-item brief sensation-seeking survey.

Data Analysis

Participant responses to the items from the aforementioned instruments were scored and coded as correct/incorrect for the multiple-choice questions of knowledge assessment (maximum of 6 points) and coded as 1 (strongly disagree) to 5 (strongly agree) for the of sensation-seeking and attitude surveys. Descriptive statistics were calculated. For sensation seeking, since the full score for the sensation-seeking survey was 20, we defined high-sensation seekers as scores larger than 10, otherwise, participants were categorized as low-sensation seekers. There were 119 high-sensation seekers and 56 low-sensation seekers.

A series of two-sample paired *t*-tests were conducted to measure the understanding and attitudes toward the impact of methamphetamine abuse before and after the intervention. Cohen's *d* values were calculated to indicate effect size. Analysis of variance (ANOVA) was also employed in order to determine if there were differences by age group, gender, ethnicity, race, and/or sensation seeking. Five independent variables included age group, gender, ethnicity, race, and sensation seeking, and the dependent variables were pre-knowledge scores, gain scores of knowledge tests, and mean scores of attitude changes toward the impact of methamphetamine abuse. The Tukey's approach was used as post-hoc analysis. We calculated and operationally defined knowledge gain scores and attitude change scores as the difference from participant's pre-test to post-test responses.

Results

Knowledge Test Performance

Pre-existing knowledge. ANOVA was run for pre-test responses from the knowledge test to assess their relationship with each of the independent variables of age group, gender, ethnicity, race, and sensation seeking (Table 1). There were no significant differences among gender, ethnicity, race, and sensation seeking at the 0.05 significant level. However, a significant difference was found on the pre-test by age group. The post-hoc test indicated that the significant differences were between adults and children. The mean score was 1.59 ($SD = 1.52$) for adults and 0.76 ($SD = 1.14$) for children. The results showed that generally adults come into the exhibit with more knowledge of neuroscience and the impact of methamphetamine abuse before the intervention. Besides, a bigger standard deviation for children which indicated a lot of within-group variation was found in the present study. The possible explanations are going to be provided in the discussion.

Knowledge gain. A series of two-sample paired *t*-tests to investigate participants' understanding before and after the exhibit were conducted. Overall, there were significances ($p < 0.0001$) between pre- and post-knowledge tests in terms of age group, gender, ethnicity, race, and sensation seeking (Table 2), which means that regardless of age, gender, ethnicity, race, or sensation-seeking personalities, the

Table 1. ANOVA results for pre-test responses of knowledge test

Source	*df*	Mean square	*F*	*p*
Age group	2	22.5303	12.22	<0.0001**
Gender	1	0.0039	0.00	0.9632
Ethnicity	1	0.0296	0.02	0.8995
Race	2	0.1202	0.07	0.9371
Sensation seeking	1	0.9241	0.50	0.4806

$^{**}p < 0.01$.

Table 2. Comparison of pre- and post-knowledge tests by age group, gender, ethnicity, race, and sensation seeking

		Pre-test		Post-test				
	N	Mean	*SD*	Mean	*SD*	*t*-value	*p*	Cohen's *d*
Age group								
Adult	65	1.59	1.53	5.47	1.13	14.84	<0.0001**	2.88
Youth	9	2.56	1.94	5.33	1.12	5.63	0.0005**	1.75
Children	101	0.76	1.14	3.96	2.17	15.15	<0.0001**	1.85
Gender								
Male	90	1.12	1.53	4.49	2.08	14.35	<0.0001**	1.85
Female	85	1.22	1.33	4.71	1.80	16.37	<0.0001**	2.27
Ethnicity								
Hispanic/Latino	7	1.57	1.40	3.71	1.38	3.88	0.0082**	1.54
Not Hispanic/Latino	168	1.15	1.44	4.63	1.96	21.41	<0.0001**	2.02
Race								
Asian	11	1.00	0.90	4.09	2.26	5.20	0.0004**	1.80
Black/African-American	19	1.16	1.64	3.79	2.32	4.86	0.0001**	1.31
Caucasian	145	1.19	1.44	4.74	1.85	20.78	<0.0001**	2.14
Sensation seeking								
High-sensation seekers	119	1.19	1.52	4.66	1.91	17.66	<0.0001**	2.01
Low-sensation seekers	56	1.13	1.24	4.46	2.03	12.37	<0.0001**	1.98

**$p < 0.01$.

participants performed better on the knowledge tasks after the exhibit. An ANOVA showed gain scores were significantly different by age group ($p < 0.05$) (Table 3). A subsequent post-hoc test indicated the significant difference of knowledge gain scores is between adults (mean = 4.20, *SD* = 1.73) and children (mean = 3.39, *SD* = 2.01), that is, adults learned more about neuroscience and the impact of methamphetamine abuse from the virtual brain exhibit than children. However, the gain scores showed no significances in terms of gender, ethnicity, race, and sensation seeking.

Attitude Changes toward the Impact of Methamphetamine Abuse

The results of the two-sample paired *t*-test showed that the participants obtained significantly higher scores on the post-attitude survey toward the impact of methamphetamine abuse on the brain in terms of age group, gender, ethnicity, and sensation seeking. However, as for race, there were no significant differences for Asians and Black/African-Americans between pre- and post-tests (Table 4). A subsequent ANOVA for attitude changes indicated that there were no significant differences among age group, gender, ethnicity, race, and sensation seeking (Table 3).

Table 3. ANOVA results for knowledge gain performance, and attitude changes toward the impact of methamphetamine abuse on the brain

		Knowledge gain			Attitude changes		
Source	*df*	Mean square	*F*	*p*	Mean square	*F*	*p*
Age group	2	11.60	3.31	0.04*	1.28	1.33	0.27
Gender	1	0.11	0.03	0.86	0.52	0.54	0.46
Ethnicity	1	6.92	1.98	0.16	0.03	0.03	0.87
Race	2	7.59	2.17	0.12	0.85	0.88	0.42
Sensation seeking	1	0.11	0.03	0.86	0.40	0.41	0.52

* $p < 0.05$

Table 4. Comparison of pre- and post-attitude surveys by age group, gender, ethnicity, race, and sensation seeking

		Pre-test		Post-test				
	N	Mean	*SD*	Mean	*SD*	*t*-value	*p*	Cohen's *d*
Age group								
Adult	65	4.22	1.10	4.81	0.44	4.19	<0.0001**	0.70
Youth	9	4.37	0.51	4.74	0.28	2.63	0.0304*	0.90
Children	101	3.90	0.86	4.22	0.77	3.67	0.0004**	0.39
Gender								
Male	90	4.06	0.89	4.43	0.74	3.61	0.0005**	0.45
Female	85	4.02	1.02	4.51	0.67	4.55	<0.0001**	0.58
Ethnicity								
Hispanic/Latino	7	4.48	0.60	4.76	0.50	3.29	0.0167*	0.51
Not Hispanic/Latino	168	4.02	0.96	4.46	0.71	5.62	<0.0001**	0.52
Race								
Asian	11	3.82	0.69	4.00	0.99	0.82	0.4316	0.21
Black/African-American	19	3.77	1.50	4.42	0.85	1.72	0.1028	0.53
Caucasian	145	4.09	0.88	4.51	0.65	5.71	<0.0001**	0.54
Sensation seeking								
High-Sensation Seekers	119	3.98	0.88	4.43	0.72	5.28	<0.0001**	0.56
Low-Sensation Seekers	56	4.17	1.09	4.56	0.66	2.63	0.0110*	0.43

*$p < 0.05$; **$p < 0.01$.

Discussion

The learning environment of museums is dramatically different from traditional classrooms. Contrary to the structured, obligated, and captive-audience learning environment of traditional classrooms, the informal learning environment of museums is free-choice, unstructured, and self-controlled (Falk & Dierking, 2000a). Falk and Dierking (2000a) continue by arguing that:

> In fact, contrary to popular belief, there was no evidence that visitors came *either* to learn or to have fun, but almost without exception visitors came *both* to learn and to have fun. The individuals who chose to go to the museum were seeking a *learning-oriented entertainment experience*. (pp. 72–73)

These expectations shape how visitors learn and what kinds of learning processes they prefer. For instance, the participants who seek learning-oriented entertainment experiences would prefer learning by doing, more interactive activities, and more self-controlled learning. Hence, how to provide meaningful and enjoyable experiences that attract and engage visitors would be the first challenge that informal education researchers encounter (Crane, 1994). Another consideration faced by researchers is dwell time. Visitors usually spend brief and unstructured time on exhibits (typically the dwell time varies widely from 30 seconds to 15 minutes, and it is believed that computer-based exhibits providing interactive interpretations and well-designed exhibits attract visitors and engender lengthy dwell time; Allen, 2004; Heath & vom Lehn, 2001), hence the learning experiences provided should be brief but fun enough (Bitgood, Serrell, & Thompson, 1994). It was under these assumptions that the exhibit, *Drugs and the Brain: A Serious Game*, which employs virtual brain simulations with a video game to teach the public impact of methamphetamine abuse on the brain, was designed.

The present study is an evaluation that helped both to assure project success as well as to provide for some evidence of visitors' learning outcomes from the exhibit. There are some interesting findings in the study that will be discussed as follows.

Understanding of the Impact of Methamphetamine Abuse on the Brain

One important question that science educators and researchers would like to know is, did visitors really learn from this interactive science exhibit that employed a virtual brain tour combined with a video game format? The results in the study indicated that participants generally performed better on the knowledge tasks after visiting the exhibit. That is, after exposure to the exhibit, participants' knowledge about the basic neuroscience concepts and the impact of methamphetamine on the brain significantly improved regardless age, gender, ethnicity, or race. Obviously, this serious game had a positive influence on neuroscience and drug use education. The same positive impact of serious games on neuroscience education is also evident in other studies (Miller, Moreno, Willcockson, Smith, & Mayes, 2006; Miller, Schweingruber, Oliver, Mayes, & Smith, 2002).

Recent research indicates that video games as an educational tool implemented into science classrooms improve students' learning (Lim et al., 2006; Squire et al., 2004). However, most research focuses on integrating serious games into formal educational settings. The present research could be seen as evidence that can be used to support the role of serious games being used in informal learning settings such as museums. The effectiveness of informal learning environments with serious games still needs to be further investigated.

The results of the pre-existing knowledge test indicated that although adults possessed more pre-knowledge than children, what the public including adults (mean = 1.59, *SD* = 1.52) and children (mean = 0.76, *SD* = 1.14) actually knew about neuroscience and the impact of drug abuse was quite limited before exposure to the exhibit. The current drug use prevention programs usually focus on the skills of training to resist drugs and peer pressures and to deal with life stresses. The knowledge aspect of the impact of drug abuse on the brain based on neuroscience research is usually ignored; and moreover, even neuroscience *per se* is usually not a topic in school science curricula. Echoing with Zardetto-Smith and colleagues' efforts (2006; 2002), the present study also tried to contribute to increasing the awareness and understanding of neuroscience through the museum visitors. To improve the neuroscience literacy of the whole society, more researchers are still required to participate and to provide their endeavors.

It is not surprising that age differences that favor adults on knowledge task performance were displayed, that is, adults gained more knowledge from this exhibit than children. Because of the differences of cognitive abilities and/or life experiences, originally children were not supposed to gain the same knowledge as adults in the study. What we would like to see is that adults could play a role as facilitators to assist learning in children. Research has indicated that the interactions between parents and children is an important factor in determining the science learning outcomes of museum visits (Allen, 2002; Crowley et al., 2001; Leinhardt & Knutson, 2004; Rennie & McClafferty, 1996). Moreover, research also found that more parent–children interactions and greater learning outcomes occurred at an interactive exhibit than others (Blud, 1990a, 1990b, as cited in Rennie and McClafferty, 1996). Vygotsky's (1978) sociocultural theory supports the belief that learners internalize and construct knowledge through aid from more experienced experts and help from the environment. In other words, with assistance and interactions, the more resources learners are given access to, the more they learn. From this perspective, adults' efforts to facilitate children's understanding in a museum is a typically socioculturally facilitated learning (Falk & Dierking, 2000b).

According to these aforementioned studies, it was supposed that parents would act as helpers/supporters/facilitators of children's learning. Though the same surveys were given to both adults and children, it was assumed that children could still learn the science concepts embedded in the interactive exhibit and understand the directions of answering those surveys because of parents' assistance. Our results ultimately indicated that though children did not gain as much knowledge as adults, they had a significantly better performance after visiting the exhibit. In other words, children did perform significant learning outcomes in the present study. Fortunately, with adults' facilitation, learning in children therefore occurred. We would suggest that videotaping of the family behaviors and observations and discourse/interactions between parents and children could be conducted and analyzed in future work to actually examine adults' facilitation.

Another important issue which should be acknowledged is the bigger standard deviation for children. After revisiting the original dataset, a bimodal distribution was found. In other words, the distribution of children's performance showed two marked peaks which were located at extremely low and extremely high values. Two explanations are conjectured. First, children with more video game experiences might perform better. Unfortunately, video game experiences were not taken into consideration in the present study; hence, we highly suggest that the groups of beginner/experienced video game users should be investigated in future work. Further, although the present study categorized participants aged from 6 to 12 into the children group, their educational levels were actually ranged from kindergartens to older elementary schools. Some might conjecture that the differences among educational levels in children may result in very different learning outcomes; however, it was not observed that older children had a better performance and children with younger ages performed worse when actually looking at the original dataset. Hence, we conjecture instead that parents' assistance again plays an important role, contributing a lot to the bimodal distribution. In other words, children with more parents' assistance performed better and children had a worse performance without parents' help. As aforementioned, adults' facilitation needs to be actually examined in the future.

Attitudes toward the Impact of Methamphetamine Abuse on the Brain

Overall, the participants performed significantly higher on the post-attitude test. However, when we broke the sample down by race, we found that Asians and Black/African-Americans showed their attitudes toward the impact of methamphetamine abuse on the brain did not change after exposure to the exhibit. First, it should be noticed that the pre-test attitudes were already quite high, so one might not be able to expect significant changes. Moreover, the samples of Asian and Black/African-American are relatively small compared to Caucasians; hence, the impact of the exhibit on attitudes of Asian and Black/African-American might be underestimated in the present study. Second, if the results were not biased, according to other studies, some possible explanations for why Asians and Black/African-Americans did not show a positive attitude change could be provided as follows.

Wallace and Muroff (2002) argue that the simple assumption underpinning current preventions that African-Americans and Whites are equally exposed and equally vulnerable to the same risk factors is not correct. Racial differences in risk factor exposure and vulnerability do exist. Hence, to develop cultural-sensitive drug abuse programs, ethnic and cultural differences in the predictors and determinants of substance use should be taken into consideration (Resnicow, Soler, Braithwaite, Ahluwalia, & Butler, 2000). Not to be designed to meet racial and cultural differences would be a shortcoming for the present exhibit that could be improved in further studies.

Further, affect and cognition are two components consisting of attitudes. This study indicates that affect-based evaluations are more accessible in memory than cognition-based evaluations of a given attitude (Verplanken, Hofstee, & Janssen, 1998). As for the exhibit, what it provided was cognition-based information which is less accessible to evaluating an attitude. Hence, trying to display more affect-based information and hands-on activities would be the next step to be considered for the exhibit.

Sensation Seeking

Another important purpose of the present exhibit was to increase the possibility of attracting and holding the attention of sensation seekers, which subsequently improve their understanding and attitudes toward the impact of methamphetamine abuse on the brain. The results in the study indicated that understanding and attitudes toward the impact of methamphetamine abuse were improved after exposure to the exhibit for both high- and low-sensation seekers. Donohew, Lorch, and Palmgreen (1998) establish a theoretical activation model of information exposure which claims attention to messages based on novelty and sensation values, and high-sensation-seeking individuals tend to tolerate more novel sensation values. Sensation value of a message refers to the ability of a message to elicit sensory, affective, and arousal responses (Palmgreen et al., 1991). Lorch and colleagues argue that sensation value 'should be an important factor in attracting and holding the attention of individuals with varying degree of need for sensation' (Lorch et al., 1994, p. 395). Novel, creative, unusual, complex, intense, graphic, ambiguous, unconventional, fast-paced, and suspenseful are characteristics of messages that could reach sensation seekers (Donohew et al., 1998). Our findings demonstrated that the exhibit satisfied the needs of both high- and low-sensation seekers for sensation, attracting and holding their attentions and subsequently improving their understanding and attitudes. However, more research for prevention programs focused on reaching high-sensation seekers are still needed.

Improvements for the Exhibit

Participants' feedback from both the pilot study and the present study additionally provided some directions of improvements for the exhibit. Control problems for driving games were the first challenge that we had to overcome. Fortunately, these problems had already been mentioned during the first weekend of testing, so we did provide more detailed instructions and guidance to the visitors in this study. However, it still didn't seem to be enough, although compared to the first weekend of testing, the participants who experienced control problems for driving games decreased. This can be seen as an indication that while the instructions and guidance may be not detailed enough, they were clearly better than the first weekend. Hence, clearer and more understandable instructions and guidance are still needed for further research.

Participants' feedback also mentioned that it would be better if there were two comparative modes for the driving games, normal versus methamphetamine-influenced condition. During the first weekend of testing, the comparative modes were included, but after the participants played the game in the normal mode, they understood what was supposed to happen and therefore delayed in going after a red light during the influenced mode. This turned out to give them a better score under the influence than in normal mode which did not convey the intended message. And that is the reason why we took out the normal mode during the second weekend of the research. Perhaps in the next study, we could employ two different scenarios for the two modes, like driving in the city under normal conditions versus driving in the country under influenced conditions. Thus, visitors could still compare the differences between these two conditions, but could not use their experiences from normal mode to influenced mode.

Another issue that was addressed was the autostereoscopic 3D display. It consists of a sheet of transparent lenses which is fixed onto an LCD screen, sending different images to each eye that are subsequently combined by the brain to create a 3D effect. This display is like a TV but includes depth, allowing the 3D image to pop out at you. It turns out that the best viewable position is in front of the screen. And this is the reason why respondents complained that sometimes it is hard to see unless they were standing in a particular spot. Therefore, providing a larger screen or having multiple screens displaying the exhibit to visitors could be considered for future exhibits.

Implications and Limitations

As a teaching and learning tool, the exhibit undoubtedly could be seen as a success since it successfully delivered basic concepts of neuroscience to the public and improved their understanding and attitudes toward the impact of methamphetamine abuse. However, it is hard to say if it is successful as a prevention program since it is just a short 15 minutes learning activity. We sincerely hope that the exhibit could be coupled with other kinds of interventions in the future, then that might make it even more effective as a tool to prevent drug abuse than just by itself. From the valuable opinions and comments of the participants, we can see that the exhibit still needs more improvements, and those are what we would endeavor to achieve in the next step. The present study ultimately demonstrates that virtual simulations and video games *per se* could be an effective tool to be used in neuroscience education.

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