Evaluating Learning and Attitudes on Tissue Engineering: A Study of Children Viewing Animated Digital Dome Shows Detailing the Biomedicine of Tissue Engineering

Anna C. Wilson, Ph.D.,^{1,*} Laura L. Gonzalez, B.S.A.,^{1,†} and John A. Pollock, Ph.D.^{2,3}

Informal science education creates opportunities for the general public to learn about complex health and science topics. Tissue engineering is a fast-growing field of medical science that combines advanced chemistries to create synthetic scaffolds, stem cells, and growth factors that individually or in combination can support the bodies own healing powers to remedy a range of maladies. Health literacy about this topic is increasingly important as our population ages and as treatments become more technologically advanced. We are using a science center planetarium as a projection space to engage and educate the public about the science and biomedical research that supports tissue engineering. The purpose of this study was to test the effectiveness of the films that we have produced for part of the science center planetarium demographic, specifically children ranging in age from 7 to 16 years. A two-group pre- and post-test design was used to compare children's learning and attitude changes in response to the two versions of the film. One version uses traditional voice-over narration; the other version uses dialog between two animated characters. The results of this study indicate that children demonstrated increases in knowledge of the topic with either film format, but preferred the animated character version. The percentage change in children's scores on the knowledge questions given before and after viewing the show exhibited an improvement from 23% correct to 61% correct on average. In addition, many of the things that the children reported liking were part of the design process of the art-science collaboration. Other results indicated that before viewing the shows 77% of the children had not even heard about tissue engineering and only 17% indicated that they were very interested in it, whereas after viewing the shows, 95% indicated that tissue engineering was a good idea. We also find that after viewing the show, 71% of the children reported that the show made them think, 75% enjoyed it, and 89% felt that they learned something. We discuss the potential impact the films might have on public knowledge, health literacy, and attitudes toward the science of tissue engineering.

Introduction

Tissue engineering: educational outreach

OUR LONG-TERM GOAL is to enhance the exposure and understanding of the public at-large to the basic biology of the human body, the health science advances of medical research, and the potential of tissue engineering. Over the last two decades, the new discipline of tissue engineering¹ has quickly exceeded the general public's understanding; while at the same time has been highlighted in the popular press and news stories.^{2,3} One way to gauge interest in tissue

engineering is to consider the response of the U.S. federal government. A decade ago, the federal government began to strive for a coherent understanding of tissue engineering as an emerging field. Established by President Clinton's National Science and Technology Council, MATES report⁴ was ultimately released in 2007 during President Bush's administration. The report defines tissue engineering as the use of physical, chemical, biological, and engineering processes to control and direct the aggregate behavior of cells (including stem cells). The report also identified opportunities for dramatic advances in tissue engineering and the related field of

This work was carried out at the Carnegie Science Center, Pittsburgh Tissue Engineering Initiative, and the Partnership in Education Duquesne University, Pittsburgh, Pennsylvania.

¹Partnership in Education Duquesne University, Pittsburgh, Pennsylvania.

²Department of Biological Science, Partnership in Education Duquesne University, Pittsburgh, Pennsylvania.

³Pittsburgh Tissue Engineering Initiative, Pittsburgh, Pennsylvania.

*Current affiliation: Department of Pediatrics, Child Development and Rehabilitation Center, Oregon Health and Science University, Portland, Oregon.

[†]Current affiliation: Green-Eye Visualization, LLC, Seattle, Washington.

regenerative medicine including as sensors, as information processing components, as diagnostics tools, and as therapies.⁴ A facet of tissue engineering relies on stem cells, which for the last decade have been heavily encumbered by misperceptions on behalf of the general public as well as lawmakers.⁵ A report made to the U.S. Congress clarified the importance of stem cell research⁶ and ultimately led to President Barack Obama's Executive Order removing barriers to responsible scientific research involving human stem cells⁷ and later the passage of *H.R. 6081 Stem Cell Therapeutic and Research Reauthorization Act*.

Since Palmer² and Bush,⁸ an increasing amount of attention is being paid to public attitudes and scientific communication around tissue engineering because of both the potential for human health and the inherent ethics questions.^{9,10} To aid in the dialog, we are developing informal science educational tools that can objectively inform the general public about the work scientists and doctors are doing to understand the basic biology of the body. In particular, we are developing animated videos for full-dome planetarium presentation on the emerging scientific discipline and medical field of tissue engineering. Tissue engineering unites biology, chemistry, engineering, and medicine to find ways to restore or replace tissues and organs damaged by disease, injury, or congenital abnormality. Tissue engineering has the potential to revolutionize health-care treatment and, at the same time, may eventually save hundreds of millions of dollars each year in associated health-care costs.

A growing number of educational outreach programs have been created that help teachers and school curriculums accommodate the teaching of the evolving science and technologies of tissue engineering such as those focused on nanoscale science.¹¹ Several undergraduate and graduate programs can be found that are teaching and training young scientists across the country. For elementary and middle school children and the general public, the use of films and animation is not new to science education; however, only a few film-based projects have been developed on tissue engineering for these audiences.¹² Other animation and film work has been incorporated into news and television shows, but because of the level of sophistication in the content, many of these news stories and publications like *Discovery* and the *New York Times Science Edition*, as well as Public Broadcasting Service shows like *NOVA* and others are accessible to only about 28% of the adult population,¹³ a 10% improvement of a decade ago.¹⁴ Further, none of the related materials that we can find specifically address fundamental concepts for school-age children and general public education and, as such, would likely be inaccessible to at least 72% of the adult population and an unknown number of children.

Our projects are the first animated digital dome shows designed to reveal aspects of tissue engineering for audiences that include children, parents, and teachers. The topics include innovations in bone, heart, and spinal cord tissue engineering with the support of stem cells, synthetic scaffolds, and growth factors. Using scientific imagery for reference, the animation style attempts to faithfully represent the basic biology and anatomy of the living tissue and cells of interest, but does so in a visually artistic way. We achieved this by bringing together a collaborative team of classic visual artists and computer graphic artists, who create the imagery, which is previewed and critiqued by cellular and molecular bi-

ologists as well as tissue engineers and physicians. The team translates the stories of medical science into a visually compelling journey through the inner workings of the normal and damaged body. The significance of our process is that it presents a new science to a broad public audience in a way that is aligned with state and national teaching standards for elementary and middle school. To achieve an appropriate balance of conventional biology and new information, we (1) provide a basic biological context of the tissue or organ, (2) discuss the basis of disease, trauma, and disability, (3) highlight current medical treatments, and (4) reveal the promise for tissue engineering remedies that harness the bodies own potential for healing.

Similar to the science fiction ideas portrayed in Richard Fleischer's 1966 Oscar-award-winning film *Fantastic Voyage*, our short animated features take the audience into the living body on a tour of tissues and cells. Using an animation style that we have cultivated and developed over the last decade, our films continue to reach beyond the previous success embodied in our own science-education interactive planetarium shows, *Journey into the Living Cell*¹⁵⁻¹⁷ and *Gray Matters: The Brain Movie*.¹⁸⁻²⁰ The learning goals of the newest planetarium shows are also complemented and supported with an array of innovative learning tools, including museum kiosks^{21,22} and teacher resources, curriculum, video games, board games, and teacher professional development activities.²³

Learning and attitudes

Previous research has shown that exhibits at science centers and related institutions are effective at teaching adults scientific information,^{24,25} and a number of studies have investigated factors related to children's learning in these free-choice learning settings, including parent-child interactions²⁶ and pretrip orientation.²⁷ The majority of studies in this area have examined museum visitor's interactions with and learning from exhibits, and few have looked specifically at video presentations of scientific information in the museum setting.

There are several advantages to presenting this material in animated video format in a planetarium and/or science center setting. First, the contextual model of learning in these free-choice settings posits that learning is more likely to occur when the design of the presentations is appealing and engaging, and when exposure to exhibits is of adequate length and intensity.²⁸ Additionally, there is an ongoing emphasis in the field of science education to present scientific information as an understandable narrative that prompts interest and exploration, rather than merely as a set of defined labels (e.g., "this is a 'cell'").²⁹ Further, the narrative needs to prompt visualization and scientific imagination.²⁹ Our approach is to tell a story through a rich set of three-dimensional (3D) images for audiences of all ages. While we cannot give the audience a hands-on tour of the organs in our body, the richly artistic graphics give everyone a visual experience combined with a dynamic soundscape that, in combination, is intended to be highly memorable.

A second advantage to our animations is that they react to a growing crisis in aliteracy and weak health literacy among millions of adults. Aliteracy has been defined by the *American Heritage Dictionary of the English Language* (4th edition) as

"able to read, but not interested." Aliteracy is ubiquitous in the United States spanning all demographics and is self-reinforcing. A new generation of adults and public school teachers are themselves more likely to be aliterate than the previous generation, and students who develop aliterate tendencies may never become strong and engaged readers.³⁰ Aliterate individuals get their information largely from television, the Internet, or not at all. However, information that is critically needed for understanding the underlying science of one's own health is often not presented well or is missed entirely.³¹ A major study conducted by the U.S. government indicated that as many as 110 million adults have weak literacy skills, a combination of illiteracy and aliteracy. Of these people, at least 75 million have poor health literacy skills³² and are present in the population at large, regardless of race, class, or even educational attainment.³³ While it is hoped that improved education will increase the rates of functional literacy over time, health knowledge can be increased in the general population through the use of multimedia materials such as animated videos.

A third advantage comes from the planetarium venue itself. Research has shown that attitude change and learning are most likely to take place when individuals are calm, when information is presented objectively, and when people are self-affirmed, or reminded of their own worth.^{29,34} The educational experience that we provide creates many of these learning catalysts by emphasizing the body's innate healing powers, which may serve to affirm the audience members by reminding them of their own body's amazing natural abilities.

Life-long attitudes about science are guided by early education experiences.³⁵ Recognizing that the science center audience has a high expectation and is motivated to be engaged in new experiences, we provide an opportunity that reinforces their behavior. Ambrose and colleagues³⁶ consider this approach when they discuss what motivates students to learn. From our perspective, engaging the mind, inspiring the spirit, and improving the self-esteem of children are intimately interconnected. Showing children that they can learn something that may have initially seemed complicated or beyond their grasp helps them realize that they can strive to learn many other things. There is substantial evidence that children are more likely to engage in career choices that have been modeled for them, as well as evidence that attitudes strongly influence the choice of a science career, especially for girls.³⁷

Animated video production process

Before any films were produced, we conducted a formative survey of over 350 museum patrons (<10 to >60 years of age) yielding 280 completed surveys of general audience attitudes and interested in tissue engineering. The study garnered 20% minority participation. We also identified the levels of interest across ages, and found that most people felt that tissue engineering was a good idea, but that ethics considerations were important and that a number of misconceptions were also reported (i.e., that protein is not part of your body).

For the purpose of audience testing, a first-edition animated video was produced using 3D animated video imagery, with a sound track and voiceover that tells the story of bone tissue engineering for badly broken bones. Both for-

mative and postproduction testing indicated that while the presentation was successful, the language of the film was too sophisticated and narrowed the range of audience that could appreciate it. A second edition, which expanded the topics to include cardiac tissue engineering, was produced in two formats. One format integrates two animated characters, a female biomedical researcher named Dr. Emily Allevable, and her cartoon sidekick robot named Regenerobot (see Supplement A; Supplementary Data are available online at www.liebertonline.com/tea). The second format continues to use the original traditional narrative educational film style, but implements a more accessible dialog (see Supplement A).

Here, we compare how these two film formats influence children's learning. While cartoons have been included in educational films for some time,³⁸ this design allows us to empirically test the influence of the addition of the cartoon characters on children's learning, attitudes, and perceptions.

Materials and Methods

Study design

A two-group pre- and post-test design was used to compare children's learning and attitudes in response to the two versions of the film. This design allows for a rigorous test of the increases in knowledge that are due to viewing either version of the film, as well as allowing for independent sample comparisons of the two versions of the film. We refer to *Dr. Allevable's Unbelievable Laboratory* as Group One, and *Tissue Engineering for Life* as Group Two.

The films

Scripts for the two versions of the film include nearly identical educational content. Figure 1A shows the movie poster from *Dr. Allevable's Unbelievable Laboratory*; Figure 1B shows the movie poster of the traditional educational film *Tissue Engineering for Life*. Figure 2 shows stills of 3D animations that are in both versions of the film. Figure 2P–R shows screen shots with both Dr. Allevable and Regenerobot discussing aspects of tissue engineering.

Participants

Participants were 266 children who were attending week-long summer science camps at the Carnegie Science Center. Summer science camp scholarships are available, and the summer camps typically attract an economically and ethnically diverse group of children.

Of the children who reported their ethnic or racial background, 10% were African American, 15% were Asian American, 72% were European American, and 2% were Hispanic. Children's mean age was 9.96 years (standard deviation [SD]=1.74, range=7.00–16.00), with the vast majority of the sample (97.4%) being 13 or younger. Only 23.6% of participants were female (74.7% male; gender data were missing for 4 children). Thirty-seven children were absent on the day that either the pretest or post-test was administered, and this incomplete data was not used. In 18 additional cases, a child had already seen the film in a previous science camp week, and this data was also not used. Complete data (pre- and post-test) were available for 229 children. Approximately half of these children ($n=114$) viewed *Dr.*

FIG. 1. Movie posters for the two versions of the films. (A) The film *Dr. Alleable's Unbelievable Laboratory*, with the animated characters that help to tell the story. (B) Traditional education film *Tissue Engineering for Life*. The participants did not have access to these posters before viewing the shows. Color images available online at www.liebertonline.com/tea

Alleable's Unbelievable Laboratory (Group One), and half ($n=115$) viewed *Tissue Engineering for Life* (Group Two). Group One and Group Two were compared on pretest variables, and did not differ significantly in age, gender, or ethnicity distribution; their reported preference for art or science education; or their preshow knowledge of the topic.

Procedures

Data from the participants were collected using paper-and-pencil questionnaires. No identifying information was collected. Each week of the summer, science camp teachers had the option to bring their students to the *Tissue Engineering* planetarium show. If a teacher chose to participate, he or she administered a 20-min pretest questionnaire to the students 1 day prior (most were done in 15 min). All children completed the same pretest questionnaire regardless of the show they were to see and could skip any question they were uncomfortable answering (see Supplement B).

After the film, teachers administered the 20-min post-test questionnaire to the students (see Supplement B). The same

post-test questionnaire was used for both groups. Both the pre- and post-test questionnaires included an item asking "What is your birthdate?" used to match participants' pre- and post-show questionnaires. Data were analyzed using SPSS[®] statistical software for Windows, to calculate sample descriptives and compute reliability, *t*-test, and correlation statistics.

Measures

Questionnaires assessing children's knowledge and perceptions of the film were developed to evaluate the two versions of the film. The development of these original evaluation tools was guided by principles of questionnaire development for children,^{39,40} and informed by age-appropriate existing science education attitude assessment tools.⁴¹ A range of item formats were used, including open-ended items, multiple-choice questions, and fill-in-the-blank, drawing, and Likert-scale items. Eight items assessing knowledge of the topic were included in both the pre- and postshow questionnaires (Supplement B). This 8-item knowledge scale demonstrated adequate internal consistency in the current

FIG. 2. Screenshots of the film and instructional animations for bone tissue engineering used in both formats of the film. **(A)** X-ray of a severely broken bone depicting bone loss. **(B)** Animation of the implantation of engineered bone scaffold to repair bone loss. **(C)** Animation of a blood capillary passing through living bone. **(D)** Colorized bone scaffold seeded with stem cells. **(E)** Animation of syringe inserted into bone marrow used to withdraw adult stem cells. **(F)** Animation depicting normal and cultured stem cell-derived bone precursor cells (blue) growing new bone. **(G)** Animation of beating heart created to depict different heart rhythms. **(H)** Arterial plaque that has ruptured leading to a natural clotting response that obscures blood flow, leading to heart attack. **(I)** Surface view of arterial that supplies blood to field of heart muscle cells. **(J)** Dying cells near clot leave extracellular matrix scar. **(K)** Tissue-engineered flexible patch seeded with stem cells helps to regrow new heart muscle. **(L–N)** Animation of the whole body with transparent surfaces to visualize bone, muscle, organs, heart, and brain. **(O)** Animation of rotating leg visualized revealing muscle and bone. **(P)** Dr. Allevable and Regenerobot discuss stem cells and their ability to grow up to be a neuron, or other cell types. **(Q)** Dr. Allevable and Regenerobot discuss real dividing cells. **(R)** Dr. Allevable and Regenerobot discuss the inner workings of bone marrow. Color images available online at www.liebertonline.com/tea

sample at pre- and postshow data collection points. The preshow alpha coefficient was 0.67 and the postshow alpha was 0.78.

Preshow questionnaire. This questionnaire was designed to assess demographic variables (e.g., age, gender, and ethnicity), baseline interest level in science and art, and preshow knowledge about the film's topic. Items were also included to assess potential personal relevance of the topic

(e.g., "Have you ever broken a bone?" and "Is anyone in your family a doctor?"). Four drawing or sketch items were also included as an additional measure of understanding of the topic. Children were given space to "draw a quick picture or sketch of what you think these things look like...(1) the inside of bone, (2) a stem cell, (3) a capillary, and (4) something that helps hearts be healthy." A total preshow knowledge score was calculated as the sum of correct responses to the eight knowledge items.

TABLE 1. PRE- AND POST-TEST MEASURES OF KNOWLEDGE IN GROUP ONE (DR. ALLEVABLE) AND GROUP TWO (NARRATIVE FILM)

	Group one: Dr. Allevable		Group two: narrative		Group differences
	M	SD	M	SD	
Pretest knowledge score	1.88	1.76	1.92	1.63	NS
Post-test knowledge score	4.87	1.91	4.69	1.91	NS
Learning score	3.00	1.80	2.77	1.76	NS

NS, not significant; M, mean; SD, standard deviation.

Postshow questionnaire. All participants completed a 26-item postshow questionnaire (see Supplement B) that was designed to assess children's knowledge of the topic following the film, as well as their perceptions of the film (enjoyment, preference for the characters, etc.). A total postshow knowledge score was calculated as the sum of correct responses to the eight knowledge items. Identical postshow drawing items were also included.

Learning score. A single learning score was calculated as the preshow knowledge score subtracted from the postshow knowledge score, with higher scores indicating more improvement. An additional individual questionnaire item was used to assess children's perception of learning ("How much do you think you learned from the movie?").

Preferences and attitudes. Participants were asked to rate their preferences for different aspects of the film on a 5-point Likert scale. To make this more understandable for children, everyday language and smiling and frowning faces were used (see Supplement B). The five choices were "Hated it," "Didn't like it," "Neutral," "Liked it," and "Loved it." These were assigned the numerical values of 0–4, with higher scores indicating greater liking. Preferences for each aspect of the film were not summed, and were considered separately. A single questionnaire item was used to assess overall enjoyment of the film ("How much did you enjoy the movie?"). Participants were also asked the following open-ended

questions: "What did you like more about the movie?" "What did you dislike most about the movie?" and "What should be changed to make the movie better?" The most frequently occurring responses to these items will be reported here.

Results

Changes in knowledge: standard multiple choice, T/F and fill-in-the-blank questions

Preshow knowledge scores were similar in Group One (mean [M]=1.88, SD=1.76) and Group Two (M=1.92, SD=1.63), as were postshow knowledge scores (Group One, M=4.87, SD=1.91; Group Two, M=4.69, SD=1.91). Both groups demonstrated significant increases in knowledge of the topic, with mean learning scores of 3.00 points (SD=1.80) for Group One and 2.77 points (SD=1.76) for Group Two (see Table 1). This learning score difference was not significantly different between the groups, $t(227)=0.96$, not significant suggesting that children learned about the topic regardless of film format. The overall difference in pre- and postshow knowledge scores was significant for the entire sample $t(228)=-24.46$, $p<0.001$, with scores increasing a mean of 2.88 points in the entire sample (Table 2).

Although learning was not significantly different between the two film groups, learning was related to other preshow variables. When children reported a higher preshow preference for science, this was related to higher learning scores, $r(225)=0.13$, $p<0.05$. Children's perception that they had learned was also significantly related to higher learning scores, $r(226)=0.19$, $p<0.05$, as well as being associated with higher preshow preference for science, $r(223)=0.26$, $p<0.001$. Perception of learning was also significantly related with children's preshow report that they wanted to be a scientist or a doctor, $r(224)=0.15$, $p<0.05$.

Changes in knowledge: visual and graphic interpretation

Children's drawings also showed some improvement from pre- to postshow questionnaire. Improvement was evaluated qualitatively based on improvement in definability of children's renderings. As the drawing items were last on the questionnaires, a number of children did not have time to create paired pre- and postshow sketches to evaluate. Of the

TABLE 2. COMPARING PRE- AND POSTVIDEO KNOWLEDGE

Knowledge item	Item type	Pretest % correct	Post-test % correct	Df	Pre-post <i>t</i>
1. What is a stem cell?	Multiple choice ^a	28	76	228	-13.20***
2. Where do stem cells come from?	Fill in the blank	1	29	228	-9.30***
3. Is there blood in your bones?	Yes/No	41	97	227	-16.75***
4. Where is blood made?	Fill in the blank	15	41	227	-8.18***
5. What is tissue engineering?	Multiple choice ^a	40	77	228	-10.38***
6. What does extracellular matrix mean?	Multiple choice ^a	13	68	228	-15.50***
7. What is a heart attack?	Multiple choice ^a	36	52	228	-4.26***
8. A growth factor is:	Multiple choice ^a	16	38	228	-6.28***
Total knowledge score (sum of all eight items)		1.90	4.78	228	-24.46***

^aMultiple choice items included five options.

*** $p<0.001$.

Df, degrees of freedom.

children who did complete both pre- and postshow drawings, at least 18 percent showed significant improvement (Fig. 3).

Perceptions and attitudes

In the formative study, when asked if they had heard of "tissue engineering," 100% of the children 10 and younger and 81% of the children 11–18 years old answered that they had not heard about it. After the children finished viewing the film we asked them, "How interested are you in learning more about regenerative medicine?" and found that 61% indicated that they were interested. Further, after seeing the film, children in both study groups reported similar perceptions of how much they learned from the movie in the two groups, how much the film made them

think, and overall enjoyment of the film (Table 3). Taken together, 89% indicated that they learned (Fig. 4A), 75% of the children reported that they enjoyed the film (Fig. 4B), and 71% indicated that the films made them think (Fig. 4D). Some children reported being scared during the film, although there were no group differences in children's report of being scared. The majority (81%, 183 children, Fig. 4C) responded that they were not at all scared during the movie, 20 children reported "a little," 10 children reported "some," and 13 children reported "a lot." Some of these children indicated why they were scared in the open-ended questions. Reasons given included, "They should say how old you have to be to get a heart attack" and "I was scared because it reminded me of my grandma's heart attack."

FIG. 3. Examples of pre- and postshow drawings from the surveys. Children's pre- and postshow responses were matched by birth date, and the example drawings were scanned from the student surveys and put in order of the question number. Note similarity to some of the images in Figure 2.

TABLE 3. PERCEPTIONS OF THE VIDEO BY GROUP

Questionnaire item	Group one: Dr. Alleivable		Group two: narrative		Group differences: t (df=223)
	M	SD	M	SD	
How much do you think you learned from the movie?	1.78	0.99	1.88	0.97	-0.75
How much did you enjoy the movie?	1.32	0.97	1.43	1.12	-0.75
Were you scared at all during the movie?	0.35	0.80	0.35	0.83	-0.02
How much did the movie make you think?	1.33	1.08	1.35	1.09	-0.10

Responses were scored as none=0, a little=1, some=2, a lot=3.

In the formative study when tissue engineering was defined, we found that 35% of the children 10 and younger and that 66% of the 11- to 18-year-olds thought that tissue engineering was a good idea. After viewing the show, the 95% of the children (both groups) reported that they thought tissue engineering was a good idea, whereas 5% of respondents indicated that they did not think it was a good idea. Of the children who thought it was a good idea, the vast majority reported that it was a good idea because it helped or healed people. When children thought it was a bad idea, the most common reasons given were that it would hurt, or that it was unnatural.

Overall, ratings of preferences for various aspects of the films were positive (see Table 4). The aspects of the film rated most positively by Group One were the 3D animations, the music, and Regenerobot, with 52% of the children rating his character a 3 ("Liked it") or 4 ("Loved it"). The most negatively rated aspect of the film was the computer-generated model of the human body (Fig. 2L-N), with 28% of the overall sample choosing 0 ("Hated it").

Open-ended questions assessing preferences included, "What did you like most about the movie?" In Group One ($n=114$), the most frequent responses from children were

that they like the robot character best ($n=21$), followed by learning about heart attacks ($n=13$), the inside of the bones ($n=13$), and learning new things through animation ($n=11$). Examples of individual responses include, "I liked flying through the bones best," "The robot dude," "Learning about blood and heart attacks," and "I liked that it took you inside the body—it was easier to understand." In Group Two ($n=115$), the most frequent responses from children were that they liked the 3D animations best ($n=16$), followed by learning new things ($n=14$), learning about the inside of bones ($n=14$), and learning about heart attacks ($n=12$).

When asked what they disliked most about the movie and what should be changed to make the movie better, the children most frequently responded that they did not like the model of the human body (Fig. 2L-N). However, in both groups the most frequently occurring response was that "nothing" should be changed to make the movie better.

Discussion

This study demonstrates that children can learn complex information about stem cells, scaffolds, tissues, and tissue engineering from the style of animated planetarium show

FIG. 4. A pie-chart representation of participant responses to the postsurvey questions (note Supplement B), (A) (Q11) How much do you think you learned from the movie? (B) (Q12) How much did you enjoy the movie? (C) (Q13) Were you scared at all during the movie? (D) (Q14) How much did the movie make you think?

TABLE 4. MEAN PREFERENCES FOR THE FILMS BY GROUP

Preference rating item	Group one: Dr. Allevable		Group two: narrative film		Group differences: t (df=219)
	M	SD	M	SD	
Three-dimensional animations of the inside of the body	2.54	1.32	1.94	1.14	3.64***
Computer model of the human body	1.46	1.41	2.25	1.35	-4.26***
Music in the show	2.19	1.43	1.72	1.29	2.56**
The narrating voices in the movie			1.81	1.31	NA
The character of Dr. Allevable	1.64	1.27			NA
Dr. Allevable's narrating voice	1.64	1.23			NA
The character of Regenerobot	2.31	1.49			NA
Regenerobot's projection	2.18	1.41			NA

Responses scored as hated it=0, didn't like it=1, neutral=2, liked it=3, loved it=4.

** $p < 0.01$, *** $p < 0.001$.

NA, not available.

that we have created. We have also shown that children can dramatically add to their visual understanding of complex systems by viewing these scientifically accurate animations, adding a new dimension to their understanding.

The principal goal of education is to prepare children for their lives as adults. Not only do children learn the basic skills of reading and writing, children learn life skills. One essential skill is the ability to continue to learn and adapt to the complex systems that are the hallmark of our modern culture. An additional challenge for teaching science is that the knowledge base that needs to be taught is constantly expanding and the depth of the complexity is growing. Given that a middle school student will mature to be a voting member of the adult public in about 4 years, educational goals need to prepare young people to make decisions regarding highly technical fields of science and medicine, even if that is not their career path. For example, understanding these advances is essential for an individual to receive the best health care. However, health literacy among adults is at an all time low.^{31,32,42} As medical treatments become more complex, patients need to have a better understanding of the basic biology of their physiology to make informed decisions about treatment options. To help meet these combined needs, metropolitan schools will often turn to class fieldtrips to local museums and science centers to complement the standard course curriculum. Thus, the science centers and museums face the unique educational challenge of meetings the needs of children and school groups as well as the accompanying adult audiences and the general public.

This report highlights our effort to provide scientifically accurate and compelling stories that communicate the basic biology and health relatedness of tissue engineering with synthetic scaffolds and bone marrow-derived stem cells. The animated videos are presented in a calm and comfortable environment, providing an enriching opportunity for learning. Children tested in this study learned a great deal about a complex topic in a short, 20-min presentation outside of a traditional education setting such as a classroom. These films present difficult and complex information through the language of the visual arts and through 3D animation. The story told by the narration and the characters is intended to invite the audience along for a tour into the biology of the living body. Although our findings that children's drawings improved must be interpreted cautiously, due to the qualitative

analysis and low response rate, it is encouraging that at least for some children, the film seems to have encouraged visualization that can be rendered. Such visualization is thought to be crucial to understanding complex systems.²⁹

The results of this study indicate that the children exhibit increases in knowledge of the topic with either film format. This finding implies that children's learning through these films is not dependent on the addition of the cartoon characters to the production. However, this study did find that, overall, children reported a greater preference for the Dr. Allevable/Regenerobot version. As Bodmer³⁵ points out, early science education experiences shape attitudes about science, and the Dr. Emily Allevable version of the film elicited more positive ratings from children, and thus has more potential than the traditional narrative version of the film to be an influential educational experience. Positive ratings may also indicate that children are more likely to consider careers in biomedical fields.³⁷ The observation that the children have a preference (greater enjoyment) for the Dr. Allevable film also suggests that the children will be more willing to view the film again and/or to view other editions of the Dr. Allevable series, thus increasing their opportunities to learn about other tissues engineering discoveries.

Many of the things that children reported liking most about the films (see Table 5) were in concert with the project aims. The evaluation also provided useful information about aspects of the film that was less preferred, or possibly unpleasant to children. The findings that some children were scared during the film and that a significant number of children disliked the model of the human body will be taken into account in the development of future films.

This study has several limitations that should be considered when interpreting results. First, given that the post-assessment was within the week of summer camp, this study does not address long-term gains in knowledge or effects on attitude. A second limitation is the absence of a true free-choice learning setting in the methodology. Children in this study did not choose to see the film on their own accord, but were required to view it by their science camp teachers, in the same way that they would if their school-teacher selected this for a field trip or an in class activity. Future research is needed to investigate the appeal of the cartoon characters and the likelihood of science center visitors to choose to view the film during a visit. These factors, as well as social factors

TABLE 5. PERCENTAGES OF PREFERENCE RESPONSES

Preference rating item	Hated it (0) %	Didn't like it (1) %	Neutral (2) %	Liked it (3) %	Loved it (4) %
Three-dimensional animations ^a					
Group one	13	5	27	25	30
Group two	17	11	40	26	6
Computer model of body ^a					
Group one	39	11	25	14	11
Group two	19	6	25	31	19
Music in the show ^a					
Group one	22	7	23	26	22
Group two	27	10	36	18	9
The narrating voices					
Group two	26	10	30	24	10
Character of Dr. Allevable					
Group one	29	11	35	18	7
Dr. Allevable's narrating voice					
Group one	25	17	33	17	7
Character of Regenerobot					
Group one	19	13	16	22	30
Regenerobot's projection					
Group one	19	12	24	23	23

^aSignificant group differences, see Table 3.

such as interactions with friends and family, are also likely to influence learning.²⁸

The key potential of this style of education is that it can reach children and the public-at-large. This style of education can help bridge the gulf between the limitation of common knowledge and the necessity of developing a deeper understanding of the biology and science of modern medicine. We have recently used this style of art and animation to develop a component of a family-centered educational program to promote independence in pediatric heart transplant recipients.⁴³ For the heart transplant patients, the percentage change in children's scores on questionnaires given before and after the educational intervention including our heart video showed an increase on average of >64%.⁴³ Achieving patient understanding and compliance to instructions is a difficult process, but we are optimistic that engaging films like the ones that we produce can facilitate patient understanding of treatment options, as has been reported elsewhere.⁴⁴ We have also begun developing companion video games, board games, expanded teaching resources, and teacher professional development workshops that complement the planetarium shows.²²

The present study of learning and attitudes can provide a methodological model for the ongoing evaluation of animated video products. It also is providing a basic model of evaluation that might be useful for other informal science education tools. Continued investigation of the effectiveness of these educational films has the potential to provide useful information about the dissemination of complex scientific information. This novel study provides a foundation for exploring the utility of richly detailed scientifically accurate animations as an educational aid in both informal science education as well the classroom settings.

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Address correspondence to:

John A. Pollock, Ph.D.

Department of Biological Science

Partnership in Education Duquesne University

222 Mellon Hall

Pittsburgh, PA 15282

E-mail: pollock@duq.edu

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