Charles Darwin Synthetic Interview: A 19th Century Scientist Speaks in the 21st Century

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Abstract: Charles Darwin is largely unknown and poorly understood as a historical figure. Similarly the fundamental principles of evolution are often misstated, misunderstood, or entirely rejected by large numbers of Americans. Simply trying to communicate more facts about Darwin, or facts supporting the principles of evaluation, is inadequate; neither students nor members of the public will care or retain the information. On the contrary, building facts into a one-on-one conversational narrative creates a memorable opportunity to learn. Here we create a digital media, self-guided question and answer 'synthetic interview' with Charles Darwin. Questions are derived from a survey of nearly 1,000 people. Answers spoken by an actor portraying Darwin are derived from Darwin's own writings. Questions on modern topics are answered by scientists, theologians, and lawyers. First produced as a museum exhibit and then later reproduced as an app (iOS/Android), the Darwin Synthetic Interview has been evaluated with more than 3,000 surveyed users, of which 69% indicated that they learned and more than 75% would recommend the experience. Students who interacted with the synthetic interview in a classroom setting found answers were unexpected and clarifying. Using a format of personal narrative, the Darwin Synthetic Interview creates a new way to engage students and the public in a process of self-directed discovery of a topic that is often considered difficult to teach.

INTRODUCTION

Biologists know, as Dobzhansky famously stated, that "nothing makes sense in biology except in the light of evolution" (Dobzhansky, 1973). In this paper, Dobzhansky went so far as to write that without evolutionary principles, biology "becomes a pile of sundry facts - some of them interesting or curious but making no meaningful picture as a whole". If this is true, why is evolution so often rejected in the United States as an explanation for a fundamental principle of nature? The answer is complex as it involves sociological, cultural, political, and religious factors. Charles Darwin and Alfred Russell Wallace did not arrive at the principles of evolution easily, rather it took both men decades of observation and patient thought to realize these uniting themes. It is not terribly surprising that without the opportunity to examine the data or to observe the evidence of evolution directly, the general public finds it easy to ignore and instead simply chooses not to think about the question. If one must think about evolution, then for most people it is easier to rely on familiar stories or aphorisms that provide simple explanations.

Humans love a good story, whether it is being able to recite lines of dialogue from a movie seen once, singing along with a tune from childhood, or the retelling of a juicy bit of overheard gossip. Graca da Silva and Tehrani (2016) have provided a compelling analysis that shows that many folktales may be embedded in the history of Indo-European cultures going back thousands of years. They assessed an extensive catalog of folktales (Uther, 2004), specifically focusing on 'Tales of Magic,' a collection of stories that includes common fairy tales. For example, the story The Smith and the Devil has a central plot about learning how to work metals. Graca da Silva and Tehrani (2016) showed through phylogenetic analysis that this story may have first been told about 6,000 years ago, coinciding with the beginnings of the Bronze Age. Bronze was first discovered from smelting an alloy of copper and arsenic, which was highly toxic to produce. Indeed, it must have seemed like magic to figure out that a better non-toxic bronze could be produced by adding the rare ore containing tin to molten copper (Penhallurick, 1986). Just imagine the fire, sparks, molten metal, and fumes-all suitable for a good story. What this shows is that a compelling story will spread through cultures and will be told, listened to, and retold, often in ways that are instructive or comforting to our human psyche. In a second and well-documented case, Nunn and Reid (2015) explore Australian Aboriginal stories that date to more than 7,000

years ago and have endured through oral tradition. In these and many other cases, it is clear that humans will cling to a story with a tenacity that supports the notion that the human brain is hardwired to maintain and remember stories. Therefore, it is no surprise that there is an inherent resistance to the discounting of oral traditions that constitute the Genesis stories, which date to about 10,000 years ago—the time that humans established agriculture and herding (Zeder, 2008) to leave behind the Garden of Eden.

While humans may be hardwired to love a good story, human experience and intuition is not predisposed to engage with the fundamental principles of science. Everyone experiences evidence of the fundamental principles of gravity all the time; a dropped toothbrush hits the floor, a ball sent high into the sky follows a parabolic arc, coasting down a hill on a bicycle is far easier than pedaling up the same hill. As such, gravity is a concept that is easily accepted and, at some level, understood. Alternatively, for most people, this is not the case in regard to the principles of evolution. While biologists value the fundamental principles of evolution, the supporting data do not generally make it into the vernacular of the storytelling of the populace. Furthermore, Darwin, the man, is generally unknown; if he is known, he is vilified by many. There is little common cultural knowledge for the non-scientist to use in establishing a narrative about Darwin, his discoveries, or the principles of evolution except to seek out and read a biography or science textbook. This lack of opportunity may contribute to the pervasive misunderstanding and rejection of evolution. For example, a Gallup report (Newport, 2014) found that in the United States, 42% of the respondents hold creationist views that humans have existed in their present form since the beginning of time. Since Gallup first started asking the public questions about human origins in 1982, the percentage of Americans choosing the creationist perspective has remained nearly the same, with slight variation between 40% and 47%; however, the latest survey conducted in May 2017 showed a drop to 38% holding the view that God created humans in their present form (Swift, 2017). Over this same period of 36 years, the percentage of respondents who maintain that 'humans evolved over millions of years and that God had no part in the process' has doubled from 9% to 19%. While some consider these data to show an improvement in the public understanding of evolution, it is nonetheless troubling that the percent of core disbelievers has been largely unmoved and that the rate of changing opinions is otherwise painfully low. Additional studies by Cooperman et al. (2013, 2015) similarly found that one-third of the Americans surveyed fully reject the view that humans evolved through natural selection. The rejection of evolutionary principles directly correlates to religious beliefs and affiliation (Cooperman et al., 2015). In a separate study by the Pew Research Center, Funk et al. (2017) explored how Americans receive science news and

found it to be largely from news outlets (54%), but only 24% feel that these general news outlets get science facts right most of the time. Funk et al. (2017) also found that Americans are most interested in news about health and medicine (70%), whereas only 26% indicated their interest in topics of evolution, with only 2% indicating a high level of interest in evolution. By contrast, most people in Central and Eastern Europe believe in evolution, with the highest acceptance in the Czech Republic at 83% (Cooperman et al., 2017).

For students in the U.S., the teaching of evolution in the science classroom leaves much to be desired. The Next Generation Science Standards (NGSS) are educational standards developed to encourage a more well-rounded, deeper, and more thorough understanding of fundamental science concepts to be taught in science classrooms across the U.S. (NGSS Lead States, 2013). Despite appearing in the NGSS from kindergarten and continuing through 12th grade, the concept that evolution is a uniting theme of biology is oftentimes avoided, glossed over, or not fully addressed in many classrooms. A nationwide study of high school biology teachers found that 60% do not take a direct stance on evolution, leading to luke-warm and incomplete instruction in this area (Berkman and Plutzer, 2011). In fact, 13% of all teachers surveyed explicitly advocated a creationist or intelligent design viewpoint, and go on to teach these views over evolutionary theory (Berkman and Plutzer, 2011). If students are not receiving complete and robust instruction on evolutionary principles, is it any surprise that they will harbor misconceptions about evolutionary theory as they mature into members of the general public?

Thus, it may be that Americans' lack of understanding of evolution has to do, in part, with the limited opportunities to learn about it. However, given the nature of the evidence of evolution, it is unlike that simply presenting more facts will bring about a greater popular understanding.

Instead of plying the public with more facts about evolution, we established an opportunity for Darwin himself to be the storyteller, to answer common questions, and to do so in a human-to-human way. To achieve this, we used the Synthetic Interview technology invented by the senior systems scientists Scott Stevens and Michael Christel at Carnegie Mellon University's Entertainment Technology Center in 1998 (Marinelli and Stevens, 1998). The first incarnation of the Synthetic Interview was a demonstration of the technology with Albert Einstein, and later researchers developed a Benjamin Franklin exhibit displayed at the Pennsylvania visitor's center in Philadelphia, PA. Pre-dating even the formative years of Siri (Bosker, 2013) and Watson (Ferrucci et al., 2013) by over a decade, the goal was to let the software accept questions, which would be best matched to a pre-recorded answer. Here, with this technology, users pose questions that are answered by "Darwin."

Our challenges were many: What questions would users

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ask and how would Darwin respond? What would happen if Darwin didn't know the answer? Finally, would people be able to learn from this? In order to identify questions that are relevant to the public's interests, a survey was conducted that asked respondents, "If you met Charles Darwin, what would you like to ask him?". From these survey responses, a curated list of 199 questions were chosen for inclusion in the interactive. Darwin's answers to each question were crafted to be in his own words, derived from his writings wherever possible; these included books, letters, and notebooks, as well as biographies. Because Darwin died before many important scientific discoveries were made, answers that required a more modern perspective were provided by a team of experts, including scientists, theologians, clergy members, and lawyers. From here, we explored the usability of the Synthetic Interview technology and whether users found it to be an engaging way to learn. Our assessments indicate that users self-reported that they did learn and were generally surprised at how much they had learned.

METHODS

IRB notification. National Institutes of Health and Duquesne University Institutional Review Board (IRB) guidelines were followed in the administering of surveys and audience testing presented in this report. No identifiable or tracking information was accumulated from any of the subjects who participated in the surveys.

Questions. Printed surveys conducted with paper and pencil on the streets of Pittsburgh, in museums, schools, and even cocktail parties, provided a wide cross-section of potential users who were presented with the question, "If you met Charles Darwin, what would you like to ask him?". Nearly 1,000 responses were collected. The proposed questions were collated to identify relevant, meaningful, and answerable questions. To supplement, the development team added a few questions that they felt the audience should know the answers to, but didn't know to ask.

Darwin's Answers. With specific questions identified, Darwin's writings were searched in order to locate any relevant material he may have generated on the subject (Agassiz, 1860; Browne, Janet and Neve, 1989; Browne, 1995; Darwin, 1831; Darwin, 1838; Darwin, 1839; Darwin, 1859; Darwin, 1868; Darwin, 1871; Darwin, 1881; Darwin, 1958; Darwin Correspondence Project; Jenkin, 1867; King, 2007; Temple et al., 1860; Tort 2001). A script was prepared of these answers (supplemental resource S1), often shortened to reasonable modern 'sound-bite' length and not a Victorian-era essay. The entire script of 199 questions and Darwin's answers were vetted by multiple Darwin historians,

including Duncan Porter, Janet Browne, and Alison Pearn (Browne, 1995; Browne, 2002; Browne, 2010; Pearn, 2016; Porter and Grahm, 2015). The editorial comments were then incorporated into the revised script. For questions that would require a modern perspective or answer, a team of modern experts (Table 1) were assembled to provide commentary. Each of the modern experts was assigned a list of questions relevant to their expertise, and they were also given the answer or commentary that Darwin would provide. In every case, the modern expert was asked to answer in their own

Table 1	Experts	and	Scripts	Reviewers
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Modern Expert		
Dr. Francisco Ayala, Ph.D.	The Donald Bren Professor of Biological Sciences, Ecology and Evolutionary Biol- ogy at the University of California-Irvine	
Dr. K. Chris- topher Beard, Ph.D.	Mary R. Dawson Chair of Vertebrate Paleontology, Carnegie Museum of Natu- ral History	
Rev. Dr. Ronald Cole-Turner, M.Div, Ph.D.	The H. Parker Sharp Professor of theol- ogy and Eth- ics, Pittsburgh Theological seminary	
Fr. George Coyne S.J., Ph.D.	Director of the Vatican Observatory (1978-2006)	
Rabbi Art Donsky	Spiritual leader of the Temple Ohav Sha- lom, Pitts- burgh	
Dr. Richard Elinson, Ph.D.	Professor of Biology, Duquesne Univer- sity	
Dr. Todd Katzner, Ph.D.	Director of Conservation and Field Res- arch, National Aviary	
Dr. Edward Larson, Ph.D.	Hugh & Hazel Darling Chari in Law, Pep- perdine University	
Dr. Zhe-Xi Luo, Ph.D.	Curator of Vertebrate Paleontology, Car- negie Muse- um of Natural History	
Dr. Kenneth Miller, Ph.D.	Professor of Biology Brown University	
Dr. Sandra Ol- sen, Ph.D.	Curator of Anthropology, Carnegie Mu- seum of Natural History	
Fr. David Smith C.S.Sp., Ph.D.	Roman Catholic priest in the Spiritan or- der and former chair of the Department of Psychology at Duquesne University	
Witold Wal- czak, J.D.	Attorney & Legal Director, American Civil Liberties Union of Pennsylvania	

Darwin Consultant who	reviewed the	script that	Darwin speaks.	

Dr. Duncan	Professor Emeritus of Biological Sciences, Virginia
Porter, Ph.D.	Polytechnic Institute
Dr. Janet Browne, Ph.D.	Aramont Professor of the History of Sci- ence, Harvard University
Dr. Alison	Assistant Director, Darwin Correspond- ence Project,
Pearn, Ph.D.	University Library, Cam- bridge, United Kingdom

words in order to provide a supplementary answer to the selected question, speaking to either Darwin's comment or from their own knowledge and understanding.

Darwin Portrayed. Professional actor Randy Kovitz was chosen to portray Darwin; Kovitz's character preparation and direction included studying biographical information about Darwin. With makeup and costuming, the actor was made to resemble Darwin at 50 years old, when he published On the Origin of Species. The script was rehearsed and then played through a teleprompter in front of the recording camera during filming while a 'key color' green screen was used in the background. In post-production, the video of Darwin speaking was manipulated to place him over a 2D photo/digital background created from reference materials to resemble

Darwin's study in Down House (Figure 1).

Separately, each of the modern experts was video-recorded responding to their relevant questions. The expert's video plays in the mirror above Darwin's fireplace in his Down House study during their relevant questions. Additionally, a collection of supplemental images, artwork, and animations were compiled and presented in the mirror behind Darwin while he was speaking, adding context and imagery to his answers.

Darwin on Exhibit. The first edition of the Darwin Synthetic Interview was released as a museum floor exhibit. A graphical user interface employed a large touchscreen computer that was made to look like a desk in Darwin's study (Figure 2), cluttered with defined objects that created categories for



Figure 1. Darwin's study is the setting for the 'Synthetic Interview'. (A) Photos of Darwin's study/salon at Down House served as reference material for a digital reconstruction. (B) The actor playing Darwin was recorded in front of a key color green screen (C) reading a teleprompter to answer each question precisely. The actor was then super-imposed into the back-ground image of Darwin's study (D). The mirror over the fireplace was used as an accessory projection space for modern experts, art, and animation.



Figure 2. Users pick questions to ask Darwin from a large touch screen interface (A) that represented key topic areas including Biographical Basics, Childhood and Education, Voyage of the HMS Beagle, Life as a Gentleman Scientist, Evolution and the Skeptics, The Origin of Species, and Modern Questions. Users tap an area of the desk and then a virtual book of questions would appear in the middle of the screen; turning pages would access all the questions of the topic area. (B) The museum exhibit used a large projection screen to display Darwin providing answers to user-selected questions.



Figure 3. The museum format of the Synthetic Darwin Interview exhibit could be easily changed for the needs of the venue. (A) The user interface is a separate large touch screen computer, and the presentation of Darwin is on a separate HDTV. (B) Darwin in a cabinet where both the user interface and Darwin presentation on the same screen. (C) A similar single screen exhibit using a smaller touch screen on a table, with external speakers.

questions. These included biographical elements, aspects of his voyage on the HMS Beagle, questions on evolution, and questions on religion and related controversies. Touching one general area would open a virtual book with lists of questions and page turns would provide access to additional questions. Providing answers from his study, Darwin is projected onto a separate screen in front of the touchscreen kiosk.

The original full museum exhibit remained on display for over six years—from 2009 to 2015—at the Carnegie Science Center in Pittsburgh, Pennsylvania. The exhibit was also presented in several other museums, including the Museum of the American Philosophical Society in Philadelphia, Pennsylvania, among others.

The digital nature of the entire project meant that both the user interface and the presentation of Darwin and the experts

could be converted and presented in other formats. As such, several different exhibit types have been created (Figure 3).

Evaluation. A PC computer based version of the application was tested in a museum with patrons asked to fill out a paper-and-pencil survey after they had interacted with the prototype exhibit (survey available as supplement S2). A total of 32 surveys were completed for the prototype assessment during the last weekend of December at a science center museum. A second more extensive touchscreen survey instrument placed near the exhibit provided an optional choice to participate with the survey (available as supplement S3). A third tool, embedded in the software of the exhibit itself, counted which questions were asked most frequently by users (total tally is available as supplement S4). The open-ended survey questions on the small-scale paper survey were

interpreted individually, being generally very explicit. The open-ended survey questions on the touchscreen survey fell into three general categories: positive, negative, and uninterpretable. The positive and negative statements were generally very clear and complete sentences, making interpretation and coding straightforward. Curiously, the preponderance of typed responses were strings of letters, silly non-sequiturs, and expletives that were not coded.

App development for iOS and Android operating sys-

tems. When the Darwin Synthetic Interview was first being designed, the iPad had not yet been released by Apple Inc. However, as soon as it was available, it was clear that such a platform would be a great tool for the Synthetic Interview format. One of the original design principles of the Darwin Synthetic Interview was that every asset was uniquely defined, essentially in the format of a big spreadsheet. The user interface specifies when and where each element shows up on the screen. Thus, the background study is one asset, Darwin's video another, as well as the gold-coin experts, other resources that show up in the mirror, and finally the pages of questions. This design principle was established with the intention of being able to create maximum flexibility so as to meet the varied needs of the museum community for kiosk design and development. While the original Darwin Synthetic Interview used a two-interface design-one computer screen or projection screen for Darwin and a separate computer touchscreen as a user interface to navigate the 199 questions and experts (Figure 1D; Figure 2)-we had also developed a one-screen version for alternate museum use, as well as home and classroom PC's (Figure 3). In the single-screen version, the questions were accessed with a collection of drop-down menus. The challenge of creating the app included a redesign of the user interface to function on a tablet or smartphone (Figure 4). The redesign for the smaller tablet and phone format, and the different aspect ratios of the different devices, required a subtle rearrangement of all key assets so that they could be readily accessible, while retaining an aesthetic. The authors and app development team explored a variety of options, finally settling on the current version that allows questions to be pulled up from the bottom of the screen. A subtle animation moves Darwin's desk and the user's view of his study when the questions are accessed.

Aside from layout, a second consideration for the app was that the entire application needed to function entirely offline. This decision was made due to the negative effects that online video streaming can have on the user experience. If the app used streaming video, a slow, spotty, or unavailable connection would cause video of Darwin to buffer, freeze, or drop out unexpectedly, greatly reducing the user experience. In fact, for a user who has serious doubts about the principles of evolution, any flaw would not simply be a flaw in the app but could be perceived as a further indication of a weakness in the theory of evolution itself. The decision to remain an offline app was a challenge due to the fact that the app contains over 4.5 hours of video and animations. Special considerations were given to the fact that the quality of the videos and animations needed to remain high, while the size of the app itself needed to be reduced in order to run smoothly on basic smartphone and tablet devices.

The app version of the Darwin Synthetic Interview allows users to swipe up from the bottom of the screen to reveal nine topic areas, which when selected will reveal pages of questions. As soon as a question is selected, the question



Figure 4. Screen shots of the app version of the Darwin Synthetic Inter-view required significant rearrangement of user interface as well as data files, yet the user experience continues to seamlessly allow all of the questions and answers to flow. (A) Main screen with tool buttons in top right corner. (B) As Darwin provides his answer, art and animation may appear in the mirror behind him in a way that complements his exposition. (C) Selecting the modern experts activates their video-taped answers, which also appear in the mirror while Darwin waits, unaware. (D) Tapping the 'Select a Topic' brings the topics page of the book fully onto the screen. Picking a topic will open the book to the relevant questions (E), which may have several pages (indicated by the > on the edge of the book). (F) Adaptation of the museum exhibit to an app required several manipulations of the user interface to fit different display ratios for the variously sized screens on iOS and Android devices.

book automatically shifts and a voice prompts Darwin with the selected questions. The mirror presents art and animation that complement Darwin's answers here in the app, just as they would in the museum exhibit. Gold coins identify the modern experts who may be available to add to or contextualize the answer that Darwin gave. Other functions in the app include a tutorial, pause, shuffle, and loop. The shuffle and loop will turn the synthetic interview into a 'podcast,' so to speak, so that the user can go hands-free and simply listen in on a series of questions posed and Darwin's answers.

RESULTS

Five different types of assessments were carried out in the project. The formative assessment was a one question survey administered by paper and pencil. The second was a paper and pencil post survey administered by docents to patrons after suing a Darwin Synthetic Interview prototype in a science center museum setting. The third instrument was a post-survey, administered via touchscreen interface in a science center museum center (no docents present). The fourth assessment was a software tool that counted how many times each Darwin question and expert comments were polled. The fifth assessment was a college student commentary written by the student after they had used the app version of the Darwin Synthetic Interview.

The formative survey was a paper survey that simply asked, "If you met Charles Darwin, what would you like

to ask him?" There was no other information on the survey that might prime or bias the respondent; for example, the word 'evolution' or a picture of Darwin's likeness was not included. As such, nearly half of all respondents indicated that they did not know who Darwin was or asked, "Who are you?". While knowledge of Charles Darwin and knowledge of evolution are not necessarily linked, this observation is consistent with the fact that even now, only half of Americans surveyed believe humans evolved (Newport, 2014). It was, however, encouraging that the survey did produce over 170 compelling questions, which Darwin could and should answer. As scientists and educators, we added a few questions that we felt would be important, but that the participants did not know to ask. This follows a standard format of assessing what the audience knows, what they want to know, and what the expert community feels the audience should know. The output of this process was a collection of 199 questions that span the basics of Darwin's biography, his childhood and education, the voyage of thee HMS Beagle, the Origin of Species and evolution, questions on evolution and the skeptics, Darwin's life as a 19th century gentleman scientist, Darwin and religion and relevant controversy, and finally modern questions.

A prototype of the interactive synthetic interview was put on exhibit at the Carnegie Science Center during a high-volume weekend at the end of December with the intention of collecting users' feed-back via a paper survey. A total of 32 surveys were completed. Questions addressed the functional



Figure 5. A paper and pencil survey at a science center museum asked patron of all ages to use the Darwin Synthetic Interview. A total of 32 surveys were collected. (A) A series of Likert Scale questions assessed the user's opinion of the Visual Effects, Soundtrack, Touch Screen Look, Touch Screen Interactivity, Questions Asked, Darwin's Answers, Answers by Modern Experts, Extra Images in the Mirror behind Darwin. (B) A five point scale from Too Little, Just Right, Too Much assessed users opinion on the Length of Darwin's Answers and the Amount of information provided. (C) Patrons were asked if they would recommend the exhibit to a friend. (n-32).

aspects of the synthetic interview, including visual effects, sound, touchscreen interface, and Darwin's answers, as well as the answers from the modern experts. Over 71% of the respondents indicated that they would like to spend more time with the exhibit. Over 81% indicated that they would recommend the exhibit to a friend (Figure 5). When asked what age group(s) the exhibit was appropriate for among elementary, middle school, high school and adults, all age groups were selected, with a bias for middle school, high school and adults. Open-ended questions gave participants the opportunity to comment on aspects of the exhibit that they liked as well as make specific suggestions, many of which were incorporated into the final exhibit.

After the fully functional exhibit was installed at the Carnegie Science Center, we also collected data through a touchscreen survey tool (supplemental S3) placed next to the exhibit (Figure 6). This allowed us to continuously collect user feedback without the need of a docent or minder. Questions used Likert scales, 'Yes/No' responses, and open-end-ed questions where users could use the touchscreen interface to type their responses using a QWERTY keyboard. Over the period of three months, 3,954 surveys were taken at the touchscreen. Results of the survey indicated that people of all ages found the interactive to be engaging and a good learning opportunity (Figure 7).

Patrons were not required to answer every question in the survey, therefore the total number of responses vary per question. On rating Darwin's answers (Figure 7A), 2,814 answers were provided, with 1,830 people indicating that the answers were 'good' to 'excellent.' When queried about the answers that the modern experts provided (Figure 7B),



Figure 6. This photograph shows both the touch screen survey (fore-ground) tool as well as the Darwin Synthetic Interview touch interface in the background. The touch screen survey instrument was placed near the exhibit, with signage indicating that we were requesting feedback from users. The touch screen survey required no docents, and generated nearly 4,000 surveys over the first three months that the tool was in use.

2,484 answers were given, with 1,592 indicating 'good' to 'excellent.' Asked if the amount of information was appropriate (Figure 7C), 2,426 responses were given, with 1,539 indicating 'good' to 'excellent.' With over 1,100 responses per question, patrons indicated overwhelming satisfaction ('good' to 'excellent') with the touchscreen interface, the actor portraying Darwin, and the accessory images in the mirror (Figure 7 D, E, F). We also asked patrons to self-report their age (Figure 7G) and hundreds of people in all of the designated age categories provided responses. When asked to indicate the age groups that the exhibit was appropriate for among elementary, middle, high school, and adults, respondents felt that the Darwin Synthetic Interview seemed appropriate for all age groups (Figure 7H).

Of the 3,120 responses to the question, "Would you recommend the exhibit to a friend?", 76% (2,372) indicated that they would (Figure 7I). Of the 748 people who selected "would not recommend exhibit" and were then prompted with a question asking why, a total of 575 provided typed comments. Interpreting their responses would suggest that 48 respondents felt that the exhibit failed because we did not give adequate or equal support to creationism and/or intelligent design, amounting to 8% of the typed comments. Another 40 respondents (7%) indicated that the exhibit was "boring," 39 (7%) indicated that it "stunk" (using various synonyms), and less than 0.1% indicated that the vocabulary was too sophisticated. Several of the typed responses were incomplete or were gibberish and could not be reliably coded. Of the 3,038 people who responded to the question, "Did you learn anything from the exhibit?", a total of 2,103 (69%) indicated that they did (Figure 7J)

The touchscreen survey also asked patrons to rate the major categories of topics (Figure 2B), which were 'Biography,' 'Evolution,' 'Voyage of the Beagle,' and 'Religious Controversy/Modern Topics;' the most popular topic was 'Religious Controversy/Modern Topics' at 36%, followed by 'Voyage of the Beagle' at 25%, 'Evolution' at 22% and Darwin's 'Biography' at 17%.

At the end of the touchscreen survey, the final question was "Would you like to add a question?". A total of 2,787 people responded, with 53% indicating yes, but with 48% posting a question/comment (1,338). Of the 1,338 typed comments, 32% constituted real and interpretable questions. Some questions deemed irrelevant were not counted, such as "Do you like pizza?" or "What do you think of Ozzy Osborne?". The vast majority of these posed questions were actually already addressed in the exhibit, but the users did not find the opportunity to ask the question of Darwin.

The Darwin Synthetic Interview software also had built-in tracking features that counted how many times a given question was asked. For the period of October 2009 through July 2010, two of the most obvious questions were asked nearly 13,000 times (Table 2): "Who are you?" and "What are you



Charles Darwin Synthetic Interview - Lampe

Figure 7. The touchscreen survey results for a three-month period. (A-F) Asked the patrons to rate the exhibit on a Likert scale of Excellent, Good, Neutral, Poor, Very Poor, N/A (Not Applicable). A. Darwin answers (n=2,914). B. Modern expert's answers (n=2,484). C. Amount of information provided (n=2,426). D. Effectiveness of the touch screen interface (n=1,279). E. Darwin as portrayed by the actor (n=1,145). F. The accessory images and animation in the mirror behind Darwin (n=1,161). G. Self-reported age. H. Age appropriateness of the Darwin Synthetic Interview; they could check all of the categories that applied. A total of 4,526 responses were tabulated, indicating that users checked more than one age range. I. Would you recommend the exhibit to a friend? (n=3,120). (J) Did you learn? (n=3,038).

famous for?". Other popular questions included: "What was your favorite food?", "How old were you when you died?", "Where were you born?", and "What did you do for fun as a kid?", the latter question getting over 8,000 hits. The vovage of the HMS Beagle was also popular with the question "What is the HMS Beagle?", attracting over 1000 hits. Interestingly, the question "How fast does evolution happen?" received almost 8000 hits, while "Do you believe in God?" received greater than 6,500 hits. Several other questions like, "What is your religion?", "Were people mad at you for publishing the Origin of Species?", "Did you ever get hate mail?", "Does evolution explain everything about how mankind came to be?", and "Who were your harshest critics?" each received about 2,000 hits. For some of these questions, even the modern experts received greater than 2,000 hits for their perspective. Over the 8 months that the counting was active, over 126,000 total questions were asked. This is important because it shows the publics compelling interest in the issues that relate to Darwin and his legacy

The question-tracking tool also allowed us to identify which questions were most popular. An interesting observation is that every single one of the 199 Darwin questions and every single modern expert was chosen at least once by users. This was not inherently easy, as each of the four main subsections presented a digital book with several pages of questions. Users had to take time to navigate through the entire collection to find the questions that they were most interested in. There was concern that patrons would have a tendency to pick the first and top level question; they did not do that. The tracking data also allowed us to identify the 23 most popular questions. These came from each topic and were then used to build the 'Lite' version of the app for iOS and Android devices.

It is interesting to note that since the app was released in the autumn of 2015, it has been downloaded over 30,000 times at the writing of this paper. The vast majority of those

Table 2. Number of questions asked and number of questions with expert answer. Question (* question in the free 'Lite' app) # of times question asked # of answers from experts The Basics *Who are you? 12623 12662 *What are you famous for? 402 *How old were you when you died? Childhood and Education 12907 *Where were you born? 8529 *Did you have brothers and sisters? 8366 *What did you do for fun as a kid? 445 *Were you a good student? *What did you like to do as a child? 565 82 *Did you have any pets when you were growing up? Voyage of the HMS Beagle 1045 8 *What is the HMS Beagle? 446 *Where did the Beagle go on its voyage? 779 *Did you get seasick? 623 *Did you meet any interesting people on your trip? 227 *Why did you name the blue-footed booby what you did? After the Beagle 307 Were you married? 399 Why did you marry your first cousin? 299 *Did you have any children? The Origin of Species, evolution, and other ideas 554 *What is evolution? 205 35 *What is the Tree of Life? 31 250 *What is Natural Selection? 99 **Evolution and the Skeptics** 89 *Are the fossils the result of Noah's Flood? 98 7988 *How fast does evolution happen? 2 **Darwin and Religion and Controversy** 6572 *Do you believe in God? 4263 2330 Is your family religious? 18 2440 What is your religion? 2659 Did you ever get hate mail? 1680 Who were your harshest critics? 1500 How did you respond to criticism? 2457 *Does evolution explain everything about how mankind came to be? 4154 **Modern Questions** 491 *How does modern technology affect our evolution? 393 385 *Should children learn your theory in school? 476

Modern Experts include: Francisco Ayala (Professor of Biology), K. Christopher Beard (Chair of Vertebrate Paleontology), Ronald Cole-Turner (Professor of Theology and Ethics), Fr. George Coyne (Director, Vatican Observatory), Rabbi Art Donsky, Richard Elinson (Professor of Biology), Todd Katzner (Director of Conservation and Field Research National Aviary), Edward J. Larson (Chair in Law), Zhe-Xi Luo (Curator of Vertebrate Paleontology), Kenneth Miller (Professor of Biology), Sandra Olsen (Curator of Anthropology), Fr. David Smith (Theologian), Witold Walczak (Legal Director American Civil Liberties Union of Pennsylvania). Note - the total number of ex-pert answers can exceed the number for Darwin answers because there are multiple expert opinions offered. downloads represent downloads of the 'Lite' version of the app, which is free. Currently, we have no tracking data on who or where the users are.

As soon as the Darwin Synthetic Interview was produced for the museum community, we simultaneously released a PC/Mac software package of the Darwin Synthetic Interview that worked on a single screen with the aid of the mouse/ trackpad. Accompanying the production of the PC/Mac software, we produced an activity guide for teacher use to accompany the software in the classroom (see supplemental S5, S6, S7). As early as 2009/10, Pittsburgh Public Schools adopted the Darwin Synthetic Interview into its standard curriculum for 9th grade. The Pittsburgh Public Schools enrollment is about 25,000, with 33% White students and 53% African-American students, with about 63% who qualify for subsidized meals. Individual teachers and schools have also used the Darwin software and have also downloaded the curriculum resources from our website. While we do not track downloads, we have had over 9,400 unique visits to our website during this last year.

While the Darwin Synthetic Interview was originally created for a science museum, the fact is that museums cater to people of all ages. Our intentional design of the Darwin Synthetic Interview was such that it would be of interest and value to people of all ages. One such example is the use of the app in college level classes, serving as a bonus assignment where the students were asked to 'meet' Charles Darwin and report back on their 'conversation' (Box 1).

Many of the college students indicated in anecdotal conversation with the instructor that they thought the assignment would be boring. In one sample of 20 college students (3rd and 4th year students), there were 38 times in their written commentary when they indicated surprise and interest in Darwin's answers. Furthermore, in this sample, there were 35 times when the students indicated that they learned something new and 54 times when they found that the answers from Darwin and/or the experts made them think in ways they had not done so previously. At least two of the students found that the 'conversation' with Darwin changed some

Box 1: Instructions of Darwin Synthetic Interview Assignment

1. Download the Darwin 'Lite' app to a phone or tablet (URLs were provided for Apple iTunes/Amazon/Google Play)

2. Pick 10 questions. The Lite version has 23 questions. For each question, identify what the question was (student can paraphrase).

3. Briefly summarize Darwin's answer (student can para-phrase).

4. Provide a commentary on what you think about Darwin (and/or one of the experts) answers.

of the attitudes about evolution, even though they had been receiving instruction on evolution since middle school. All who participated found that they had fun and learned a lot (selected student comments in Box 2).

DISCUSSION

The Darwin Synthetic Interview was envisioned as creating an opportunity to have a conversation with Charles Darwin directly. It was important that the questions were genuine and relevant to people's interests, and that the answers that Darwin speaks were true to his own words. The technology needed to be free of glitches and bugs; it had to work correctly every time. Furthermore, the whole presentation had to have high production value; it could not look or sound 'homemade.'

The original design concept of Synthetic Interview technology developed by Carnegie Mellon University's Entertainment Technology Center (CMU/ETC) was created more than 20 years ago, presenting synthetic interviews with Albert Einstein and Benjamin Franklin, as previously mentioned. These exhibits allowed users to enter (type) their own question and receive a pre-recorded answer that the software deems is most relevant. The strength of the software and the conversational reality created relies on anticipating the questions that people will ask. Unanticipated questions can lead to off-base or even silly answers. Anticipating foolish questions, and having the actor reply, "I don't know" or "I'm sorry I can't answer that," can ultimately diminish the overall user experience. Ill-advised questions and non-answers make the experience a novelty and not a learning opportunity. With this in mind, we decided that an exhaustive survey of upwards of 1,000 people would provide us with a range of potential questions that we could work with. We would also seek out people of all ages and backgrounds, in order to get a varied and well-rounded sample pool. We did receive plenty of silly questions, but we also received a lot of people asking, "Who are you?". In the end, we had a strong collection of 199 useful and compelling questions that we could then pose to Darwin.

Sourcing and creating Darwin's answers needed to be done in a deeply scholarly way so that we could affirm that what the actor was stating on camera was likely to be an answer that Charles Darwin himself could have or would have given. To establish that level of certainty, we researched Darwin's extensive collection of available and digitized writings. These included his published books (Darwin, 1831; Darwin, 1838; Darwin, 1839; Darwin, 1859; Darwin, 1868; Darwin, 1871; Darwin, 1881; Darwin, 1958), Darwin's digitized notebooks and personal letters (Darwin Correspondence Project), as well as other biographical sources (Browne and Neve, 1989; Browne, 1995; Browne, 2002). The finished script was then vetted by three distinguished

Box 2: DARWIN Q/A: - college student paraphrased question, answer and student's own comment (unedited – used with permission)

Question: "Should children learn your theory in school?"

Darwin's answer: Yes, and also geology, zoology, botany, and physics as well. Otherwise, how are children going to understand natural world? Are there places where children do not learn these things?

Comment: In middle school when I was first learning about natural selection and evolution, a few students brought in notes from their parents requesting to be [exempt] from this teaching. I found this perplexing because I was never of a religious upbringing. The school did not allow these students to be exempt from this lesson and I know that a few actually changed some of their beliefs because of it. I strongly believe in the teaching or natural selection and evolution and think it results in more intelligent adults that can make better decisions about things happening in the world.

Question: "What is natural selection?"

Darwin's answer: "Natural selection is a law of nature that leads to adaptions in all species....It is important to understand that individuals of every species vary slightly from one another and that this variation is passed along from parent to offspring."

Comment: This is probably the best definition of natural selection that I have seen. Natural selection is so important to biology because you get to truly understand how evolution within species takes place. It's something you learn about very early on within a biology education. This is a great definition of the word.

Question: "What is the Tree of Life?"

Darwin's answer: "The Tree of Life is a metaphor for how I think evolution takes place."

Comment: I knew Darwin had a lot to do with evolution and natural selection, but I did not know that he contributed to the tree of life.

Question: Were you a good student?

Darwin's answer: "No, not really. The things taught to me as a child was mainly classic education. I much rather wanted to learn about natural history which is about nature. I only learned this when I got to university."

Comment: I understand not being interested in certain subjects while attending school. Studying nature is definitely an interesting subject. It is incredible how beautiful the world is, all on its own.

Question: "How fast does evolution happen?"

Darwin's answer: Darwin stated that evolution happens very slowly because nature is not something that ever acts quickly. **Comment:** I thought Darwin's answer would be more complex for this question, but his simple response makes sense.

Question: How fast does evolution happen?

Answer: Darwin says that it is a process that happens slowly, over time considering that nature only moves at a constant speed. (The experts, while largely agreeing with him, also point out that evolution can happen at a much more rapid pace. Some cite such examples as insects and fish, most pointing solely to antibiotic resistance as a rapid form of evolution.)

Commentary: This was a prime example of why the expert answers are incredibly helpful. In this instance, Darwin is not completely accurate in his statement. As such, the experts can still largely agree, but offer relatable examples of the opposite. Antibiotic resistance is a known problem that many people are familiar with, so explaining that it is a rapid evolution not only educates people further on the issue, but drives home the overall power behind evolution.

Question: Were you a good student?

Darwin's answer: Darwin stated that he was not a good student! He did not like learning only the classical subjects like Latin but instead wanted more natural sciences.

Comment: This is shocking! Darwin was such an intelligent man that I just assumed he was always a good student.

Question: Do you believe in God?

Answer: Darwin claimed that, as a young boy, he was quite devout. However, the more he studied as he grew older he became more what he called "agnostic." He found his belief became more about weighing the evidence on both sides, but unable to determine a correct answer from that. (Experts agree that the older he got, the more he turned from devout Christianity—however, he did not make others uncomfortable for believing. They also mentioned that he actively kept people from using his evidence for evolution as evidence to disprove God.) **Commentary**: I was unaware of the answer to this question previous, so I found it quite intriguing. There was something quite compelling in that, despite what many devout Christians would think regarding evolution, it didn't cause him to completely lose faith. When the experts added that Darwin also actively kept people from using his evidence to disprove God, I was equally surprised. Therefore, I highly appreciated the "faith" argument presented by the one expert, reminding people that it is possible to believe in both God and science. That is something I think more people need to understand.

Overall take away: I really enjoyed this app, far more than I expected to. I think it has a lot to offer to anyone—whether they know a lot or next to nothing about Charles Darwin. I'd be into other interview type apps in the future, maybe incorporating some female scientists.

Darwin historians (Table 1), and suggestions and corrections were incorporated into the script accordingly.

To stay true to the spirit of an interview, we did not want to allow Darwin to speak or comment on things that he did not know about, such as modern topics like genetics or DNA. These modern discoveries were made well after his lifetime. It is here that we added a new dimension to the Synthetic Interview framework: allowing modern experts to participate in the conversation. The experts (Table 1) were given selected questions that were germane to their expertise. In advance of filming, they were asked to review the question and review the script of what Darwin would say; they were then given the opportunity to comment on either the answer that Darwin provided or simply provide their own answer or commentary. In both the user survey and in the tally of questions asked, the experts' responses were viewed and appreciated by users. While Table 2 shows some of the most popular questions asked of Darwin over the course of a few months in the winter of 2009/2010, the supplemental data shows that while Darwin was asked questions nearly 112,000 times, the experts (who are not available on every question) were asked questions nearly 14,000 times.

Beyond the production process of developing Darwin's script of answers, the identification of both the modern experts and an appropriate actor to portray Darwin was an integral part of the development process. The identification of a professional actor, his training, costuming, and makeup helped in establishing the look and feel of Darwin. Next came the set and stage dressings; in this case, it was best to create that setting digitally. Similarly, the supplemental art and animation were created and presented digitally. The integration of the video, digital background, and supplemental art and animations helped to create a visually appealing and user-friendly interface. An easy-to-navigate interface, with questions that could be located and selected quickly, was critical to the success of the app. In addition, performance standards such as off-line capability, reduced file size, and multiple distribution platforms made the app compatible with almost all mobile devices, thus greatly expanding the number of people that are able to access the app and its contained information. By making sure that the app runs reliably, we removed any potential criticisms of the theory of evolution that could have arisen from a faulty or poorly designed app.

The audience surveys indicated that several dimensions of the exhibit/app were successful. As previously mentioned, a small percentage (48 out 3,120, or 1.5%) indicated that the exhibit failed because we did not give equal treatment to creationism and/or intelligent design. On the other extreme, twice out of 575 written comments, patrons questioned why we would depict a Christian Bible or have any religious commentary in the exhibit. To be clear, nowhere in the Darwin Synthetic Interview is there any commentary that gives support to intelligent design or creationism. On the contrary, Darwin makes his own case (Darwin, 1958). Furthermore, the modern experts, including scientists, clergy and theologians all make the distinction between faith and belief, and the fundamental principles of science.

We have demonstrated that careful planning can allow for a digital media design that has the flexibility for unfunforeseen possibilities. As noted, the design on the Darwin Synthetic Interview began well before the iPad and other tablets were released, and yet, our open design parameters facilitated the transition to these platforms at a later date.

We have also found that the design principles and the iterative audience evaluation has led to an overall outcome that the development of this digital tool allows people to learn about the history of science and how science can be added to with continued research by future generations. Inherently, development of this digital media experience allows people to see Darwin as an individual and a human being. Hearing about his life and times 'in person' and in an engaging narrative of short personal stories allows users to come away with surprises, such as he was a bad student, a married man and loving father, and a person very much like many of us. This humanization creates greater access not only to the history of science, but also to the principles of evolution. As such, the Darwin app creates a very broad and accessible opportunity for people of all ages to engage with evolutionary principles-they can even have Darwin in their pocket.

ASSOCIATED CONTENT

Supplemental information is available, and a free version of the app can be accessed for download for iOS or An-droid devices at http//thepartnershipineducation.com/DawinsInterview.html

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ABBREVIATIONS

iOS: Apple iPhone/iPad operating system; NGSS: Next Generation Science Standards; HMS: His Majesty's Ship; CMU: Carnegie Mellon University; ETC: Entertainment Technology Center

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