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Why Teach Manufacturing in a Museum?*

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A growing gap between technology use and technology understanding in a consumer society creates a need to educate the general public about manufacturing—the backbone of a strong economy. This paper describes development of a museum exhibit: a visitor-centred informal education experience highlighting the principles of modern manufacturing. The exhibit architecture reflects three principal engineering activities involved in creating consumer products: product design, manufacturing and marketing/business. It explains how these fields interrelate using as an example a well understood product—a customizable pen. Each activity is implemented via two complementary components: an interactive computer game and a physical display environment, which complement each other. The results of an observational study and analysis of the data gathered through a data collection mechanism built into the game are also provided, suggesting a successful achievement of initial design goals.

Keywords: Manufacturing education; informal learning; educational outreach; museum exhibit design; educational software

INTRODUCTION

DESPITE THE steadily increasing dependency of modern societies on technology, society-wide understanding of technology (necessary, for example, in informed and critical decision-making) is usually lacking. Since about 70 per cent of Americans are past school age, updating their technological literacy requires access to opportunities outside formal education. Younger generations have yet to develop their technological skills and interests, but opportunities for that in a structured, precollege education are limited. The importance of inducing technological literacy and interests in young people cannot be overstated, as it impacts on the potential future supply of engineers and scientists.

Being avid consumers of manufactured products, contemporary American youths are very familiar with the wide variety of them due to the efforts of marketing campaigns, advertising media or their own use of the Internet. However, as they buy and use today's products, they simultaneously hold no concept of how these products came to exist or how they were made. Overall, the general public's knowledge of manufacturing is limited; also its perception is really outdated (usually stuck in mass production concepts) and unappealing. This lack of knowledge creates a demotivational barrier preventing many potential students from entering the field. Such a knowledge gap creates an opportunity to educate the general public about what constitutes modern manufacturing.

This paper describes an effort to bridge the technological literacy gap, currently under way at the NSF Engineering Research Centre for Reconfigurable Manufacturing Systems (ERC/RMS) at the University of Michigan. In this endeavour a museum exhibit, offering a visitor-centred informal learning experience, highlighting the principles of modern manufacturing has been created, prototyped and tested. An innovative data gathering mechanism, embedded in the exhibit, was used to provide a snapshot of the individual visitor experience and also enabled more detailed demographic and performance analysis.

EXHIBIT GOALS

The main purpose of the exhibit is to educate visitors about the processes in three fields crucial to industrial production—product design, manufacturing, marketing—and how these fields are intertwined in development of manufactured goods. A secondary goal of the exhibit is to introduce children, especially girls, to the types of profession found in these areas so they may consider them as future career choices [1]. For either of these goals to be attained, the proposed exhibit must accomplish three tasks:

1. **attract** visitors;
2. **motivate** them to become engaged with the exhibit;
3. **facilitate** the acquisition of knowledge, understanding and attitudes the exhibit is designed to convey.

EXHIBIT OVERVIEW

The exhibit station consists of two main components: a set of interactive computer games and an

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Fig. 1. The 'Design Station' exhibit in a museum setting

exhibit kiosk, which constitutes both the physical display environment and houses the computer equipment [2]. These parts are designed to complementarily satisfy the three, previously mentioned goals of exhibit design. The physical display environment is developed to attract the visitors and support the knowledge acquisition by presenting content materials and graphic instructions for the games. The game software is the primary vehicle for visitor engagement with the exhibit, and it is also its core component where the majority of knowledge acquisition is facilitated. The exhibit is intended for participatory, informal learning institutions, and as such was designed to target the majority demographic visiting those venues, children of the ages 6–12 [3]. Thus the terms 'visitor' or 'user' employed later on in this text should be interpreted as a reference to a member of this target population (see Fig 1).

The kiosk design, providing an external environment in support of the gaming software, is essential to help guarantee the involvement of visitors with the software content, but it also provides background information. To stand out in a usually crowded museum environment, and create an attraction point competing with other exhibits, the kiosk design has an appearance directly related to the software content. The physical form of the kiosk is derived from everyday objects (e.g. a mug containing pens and rulers). The distinctive appearance creates a visual focus by leveraging these objects in exaggerated scale and bright colours. Additional board space is filled with background materials, related to the contents of the games (see Fig 2).

The gaming software was developed with the

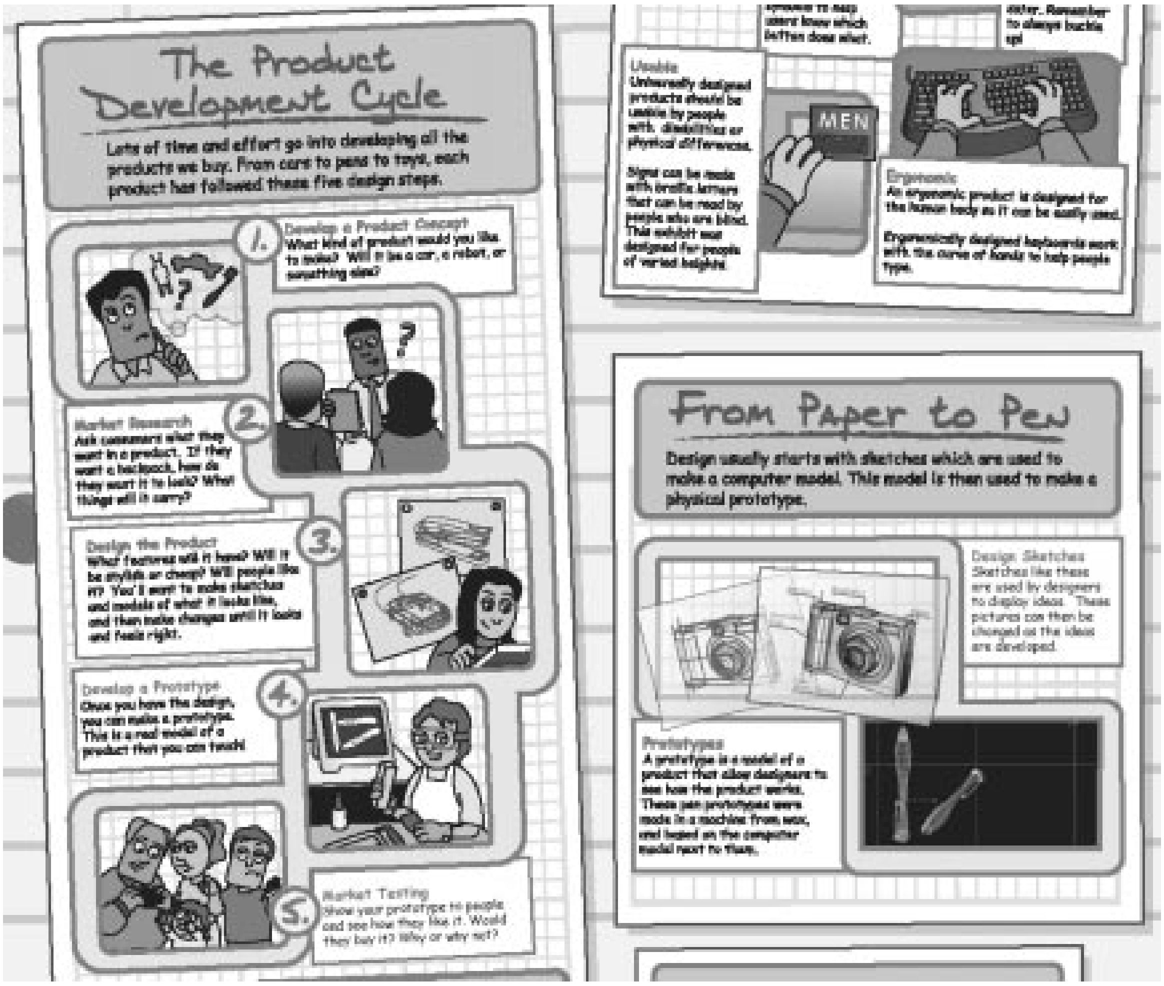

Fig. 2. Background information in the exhibit on product development.

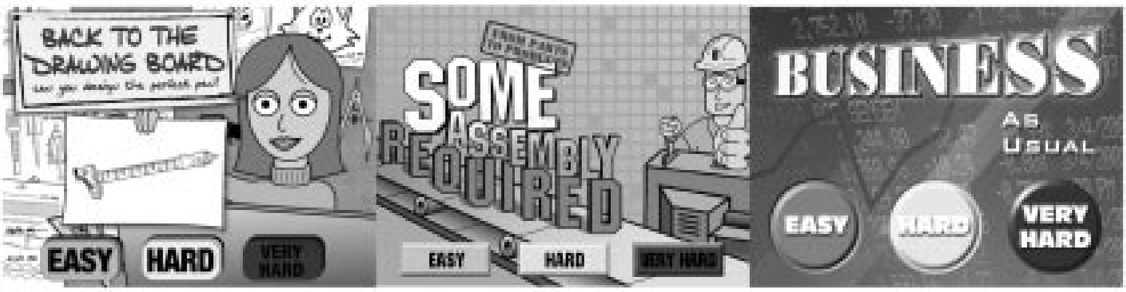

Fig 3. Opening screen shots from the three games

aim of appealing to the target audience; its content takes into account such audience members' perspectives and levels of understanding. Selected processes found in product design, manufacturing, and marketing are presented by interactively leading the user through the development cycle of an example product, specifically, a customizable pen. The selection of a pen as an exemplary product was deliberate: due to its simplicity and ubiquity it is well understood, and yet it enables the presentation of more complex concepts related to its design and manufacture. The interactive tasks that the user is asked to complete are simplified versions of tasks found in the real-world professions represented in the games, or tasks that encapsulate some of the ongoing concerns of professionals in that field.

The three games intended for this exhibit, *Design Station, Some Assembly Required,* and *Business as Usual*, have environments set in the offices of a design firm, the floor of a manufacturing plant, and a marketing office, respectively. Each of the games follows a common structure: the player is greeted by an avatar representing an employee of the environment, who introduces the setting and explains in general the type of work that is engaged in that environment. The host avatar then explains to the user that the host will need the player's help in completing a task in the environment, and explains how the task is to be executed (see Fig. 3).

Upon completion of the in-game tasks, the user's performance is rated and he or she is given detailed feedback about the basis for his or her score. An assessment of the user's comprehension of concepts and terminology presented in the exhibit is incorporated into the game under the guise of a bonus quiz. Transparently to the user, the game is anonymously recording his or her in-game actions for later analysis to aid in the assessment of the exhibit.

ATTRACTING VISITORS

The role of informal learning environments, particularly museums with interactive science exhibitions, has been argued in contemporary theories of education [4, 5]. The constructivist theories of learning suggest that informal learning allows a more incremental development of concepts in the human mind. This development occurs with an active involvement with the knowledge source, which represents an alternative to passive learning. Interactive science exhibitions are suggested as one source that appeals to and motivates children to learn with active involvement and interaction.

The Exhibit Kiosk consist of two main physical parts: panels that hold the game theme and instruction graphics, which stand out as an oversized 'notebook', and the case housing the computer equipment and presenting the game to visitors, which stands out as an oversized 'coffee mug holding pens and rulers'. These parts are designed to go beyond the conventional and straightforward manner of fulfilling the basic requirements. The appearance of the 'notebook' and 'coffee mug

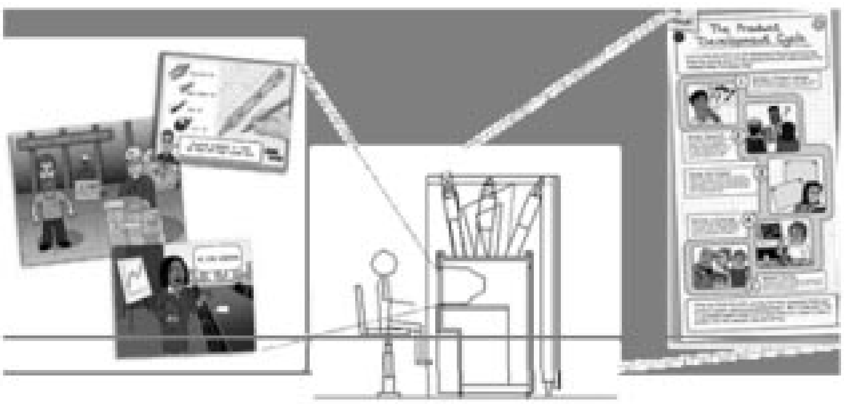

Fig. 4. Overall exhibit architecture

holding pens and rulers' in the museum gallery, represent the familiar figures of two objects in daily use , yet in an odd scale and context. This appearance of the exhibit kiosk is deliberately intended to attract the view of visitors among other exhibition elements in the museum (see Fig. 4). As it has been argued in perceptual and cognitive processes, the way people show an interest in some environmental information involves the process of recalling familiar images stored in internal representations in the mind. It has also been argued that too much familiarity create a monotonous effect and does not stimulate the attention [6]. For this purpose, the cylindrical case that holds the computer screen and equipment was designed and built as a blue coffee mug, with objects like pens and rulers with bright colours attached to it. Thus, the odd scale of familiar objects positioned in a museum context along with the use of bright colours is strategically planned in the design scheme in order to direct visitor attention and interest to the exhibit kiosk, which can be seen as the first step of facilitating knowledge acquisition.

In addition, the 'notebook' and the 'coffee mug with pens' recall the products that come into existence as a result of engineering design and manufacturing processes, which is conveyed in the *Design Game*. This also provides a necessary connection in children's mind between consumer products and processes that bring these products into existence. It has been suggested that this design extends the straightforward appearance of an interactive exhibit accessible by only a computer screen and a mouse on a table. The screen is embedded into the 'coffee mug', and the game can be played just by touching the screen. Moreover, the cylindrical shape of the coffee mug allows young visitors to have a collaborative experience with their parents and friends. Initial observations show that up to four people can have a visual contact with the game at the same time. The height of the coffee mug, and therefore the vertical position of the computer screen, enables access not only by children but also adults and handicapped persons.

Some of the previous research on exhibition types and their components proved a connection between knowledge acquisition and the ways in which exhibit types and their components are organized. The results show that exhibits which encourage more participatory engagement from visitors and which involve a greater number of senses in this engagement, through components like real objects and sounds, are more effective in transmitting knowledge. These studies classify the exhibition components in a range extending from the most 'abstract' and the most 'concrete'. Hence an exhibit with only text on a flat panel is considered the most abstract, whereas an exhibit with objects, visual materials, representations of reality and interfaces allowing sensory involvement is defined as the most concrete. The results proved

Fig. 5. Screen shot introducing the market research task

that a concrete exhibition has the most significant effect on knowledge gain. In this context, the *Design Station* kiosk can be recognized as having well-defined features See Fig. 6). In addition, the layout of the graphical material located on the 'notebook pages', presents the game theme and instructions precisely. For this purpose, text and the graphics are organized in information chunks [6]. Cognitive theories suggest that the human mind has the ability to most efficiently process information organized into 3–5 information chunks. The question of how the *Design Station* kiosk attempts to accomplish the other two tasks needed for transmitting knowledge, to motivate users to engage with the exhibit and to facilitate an understanding of the presented material, is discussed further in this paper, along with how success at these tasks can be assessed.

MOTIVATING VISITORS

The purpose of motivating visitors to interact with the exhibit is relatively straightforward: prior research shows that the longer a visitor interacts with an exhibit, the greater the possibility that learning has been facilitated [7].

The power of narrative, first-person stories to engage visitor interest in a museum exhibit has long been acknowledged in museological research [8]. To capitalize on this, each game begins with an on-screen character greeting the player and introducing him or her to the setting, story, and goals of the game (see Fig. 5). The player is then invited to act out the story that has been introduced. In the case of *Design Station*, an employee of a design firm invites the user to helps to conduct market research and then helps the firm to design pens that are likely to be a market hit (and sell well). By conducting this market research, the user discovers what qualities (such as affordability, durability, styling, etc.) would positively or negatively affect the buying decisions of customers in the target market.

The design process is somewhat abstracted from

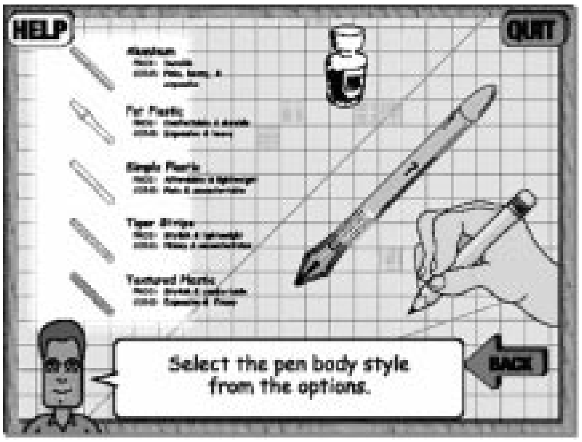

Fig. 6. Screen shot from one of the steps in the pen design process.

Fig. 7. Screen shot of the in-game bonus quiz.

what would occur in real life, in that a user chooses from pre-established options for the tips, grips, bodies, caps and inks to be used in the pen design. Each of the pen parts has distinct attributes that either match or conflict with the qualities the market research subjects requested, allowing for 1,953,125 different pen designs, and the user must engage in the nontrivial task of selecting the parts that would best reflect the desires of the target market (see Fig. 6). By placing the user in a goal-based 'embodied story', or a narrative where the visitor is interactively playing the central role, the intent is to motivate and engage the visitor and to encourage a lengthier involvement in the game [9].

Another strategy to lengthen the visitor interaction time draws from current theories on the impact of affect. Attractive, well-designed interfaces/environments have a positive effect on a person's emotions, and in turn these affective qualities impact a person's performance with that interface/environment, increasing the amount of time that they are likely to pursue a task that is difficult [10]. By providing an interface that is brightly coloured, largely pictorial, and cartoon-styled, we expect visitors will linger and explore the game (see Figs 3 and 5).

Special attention must be given towards implementing strategies to motivate the participation of girls, because girls are anecdotally less likely to become engaged by technology-heavy science centre exhibits [1, 11]. Children are documented as being able to recognize early on which computer games are 'intended' for boys, and which are 'intended' for girls, judgments that are largely made on the basis of the artistic and colour schemes used. In addition to initial impressions, some of the documented reticence girls have towards computer games is a result of the structure of the games themselves; there is some evidence that girls tend to prefer games that require cognitive skills that girls naturally possess, like matching, memory, and verbal skills, and that they prefer games that centre on creation rather than destruction [12, 13]. Even the means provided for playing the game can introduce bias: girls seem to have more problems with certain input devices—although females show equal performance to males with kinaesthetic input devices like touchscreens, they perform markedly worse with an abstracted input device like a mouse.

A special effort has been made to design the games to appeal equally to both genders. The graphic styles that skew towards any obvious gender stereotypes were eliminated, and the final design is based on neutral and primary colours in cartoon style. In the *Design Station*, the in-game goal is to read the comments of potential consumers, remember their preferences, and later select pen components that best meet the majority of these preferences. Task performance thus depends on the verbal, matching, and memory abilities of the user, to better enfranchise female players. A touchscreen interface (instead of a mouse) was used to level the input 'playing field'.

FACILITATING LEARNING

There are three main types of topics that the educational games are intended to convey: factual knowledge about a career field, such as common job titles and certain key vocabulary terms, functional knowledge about a career field, such as a task or process one might go through in the field, and a rudimentary understanding of the semiotic domain important to the career field.

Some of the factual knowledge is situated in appropriate contexts within the game's story, because the use of vocabulary terms in the context of an authentic activity helps with the acquisition of those terms [14]. The bulk of the factual information, however, is presented in a different modality, namely in print on the physical display housing the game. Effort has been made to make these labels as clear and concise as possible, so that acquiring knowledge from them is as smooth a process as possible. The in-game bonus quizzes, which reference this factual content, incorporate three of Gagne's instructional techniques to help users acquire the knowledge. These quizzes provide

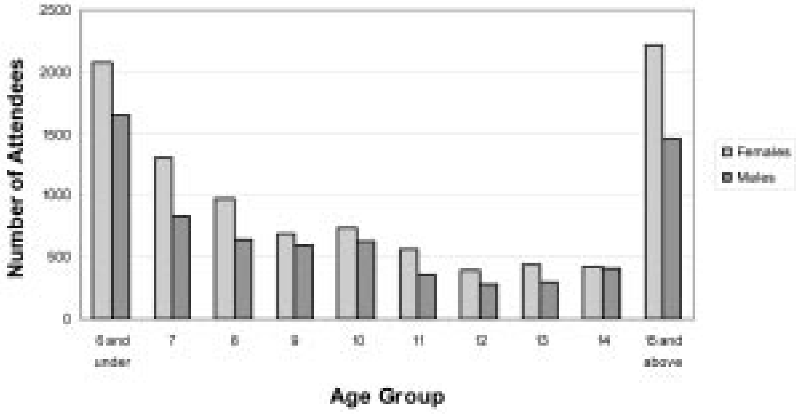

Fig. 8. Demographic distribution of game players for the data collection period of 12 months

an opportunity for the students to engage in (3) retrieval of information they should have gleaned from the game or the physical display in order to (6) respond to the quiz. Moreover, the immediate disclosure of the correct answers, with an explanation of why the answer is correct, provides (7) reinforcement (see Fig. 7) [15]. If the player is accompanied by friends or family members, the presence of easily visible factual information on the physical exhibit allows the companions to aid the player in answering the bonus questions, adding a potential social dimension to aid the learning process.

The acquisition of functional knowledge, an understanding of how to execute a task, can be best facilitated by placing the player in a situated, goal-based scenario [16]. The game's goals have been designed to align with goals that are important to the career field being depicted, and the reward structure embedded within the game is designed so that the user must construct an internal understanding of the required tasks in order to score well. In *Design Station*, the user's score depends on how well they have designed a pen to meet the needs of the people they interviewed in the mall. The more people they were able to interview, the more likely it is for the user to have formed a clear picture of the needs of the target market, thus implicitly stressing the importance of thoroughly understanding a market before creating a product to be sold in it.

It is also planned that this understanding will be enhanced and reinforced by visitors' attention to the exhibit kiosk, in particular to the graphic information on the 'notebook pages'. This graphic information is designed to summarize the game topics, and to outline the chunks of information with concise text and graphic illustrations.

IMPACTING FUTURE CAREER CHOICES

One important role computer games can play, a role that is more difficult for other forms of media to take on, is to serve as a semiotic primer for a real-world scenario or environment. By structuring the game as a first-person role-playing experience, we support the cognitive process in which '. . . being (or having been) a member of the affinity group associated with the precursor domain facilitates becoming a member of the affinity group associated with the other domain, because the values, norms, goals, or practices of the precursor

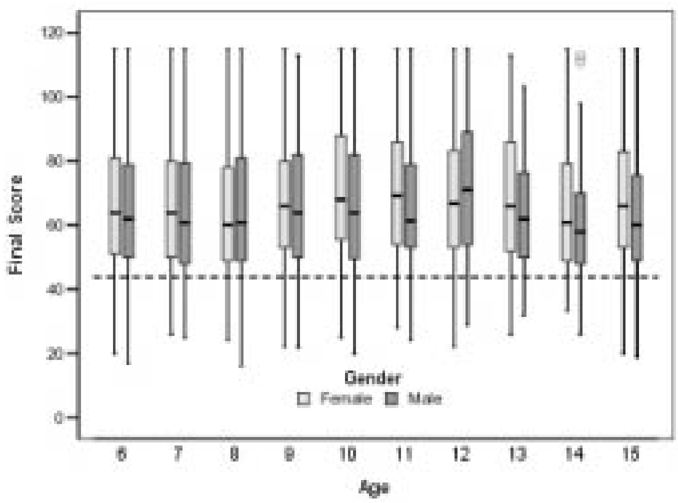

Fig. 9. Age and gender game play performance (dotted line is at the random chance level)

Table 1. Correlations between collected data dimensions

	Gameplay time	Game score	% of clues revealed	% of clues used by the user
Gameplay time	1.000	0.354	0.328	0.285
Game score		1.000	**0.492**	**0.911**
% of clues revealed			1.000	0.534
% of clues used by the user				1.000

group resemble in some way the other group's values, norms, goals, or practices' [17]. In other words, we hope to prime players to consider a career in the represented field by inculcating them with a primer of that field's semiotic domain, and we do so by engaging them in a task found in that domain, because '[in general] it is often easiest to explain what a domain is about to prospective members of a community by letting them complete a task in the domain'. [16].

ASSESSMENT OF VISITOR BEHAVIOUR

In an attempt to gauge the success of the exhibit, two complementary visitor study approaches were taken: an observational study, conducted by a human observer, and the passive logging of in-game visitor behaviour, recorded automatically by the game software. The specific form of the second observational approach was drawn from another study designed to capture the relative engagement levels of children visiting science centre exhibits [11]. This study design was then expanded to capture and codify the social context of any observed visitor interest. The second approach, passive data logging, is to some extent equivalent to the website 'hit' data, recording which game elements the user tapped on the touchscreen monitor and at what times these elements were touched, as well as certain relevant details about the current game scenario. For a limited span of time, the game also asks the user to input his or her age and gender, so conclusions might be drawn about how different demographics respond to the game [18].

The user activity logs provide a wealth of data—the 12 month data collection period has provided records of use from 16,983 visitors [19]. That accounts for 11.46% of visitor population in the museum over that period. It also needs to be indicated that the museum has over 250 exhibits on display, all competing for the attention of the visitors. The number of visitors also indicates the size and impact of this type of outreach effort (see Fig. 8).

The data indicate some performance differences amongst visitors that are attributable to both age and gender (see Fig. 9): more females than men played the game, 57% to 43%, a trend that held across virtually all age groups. Interestingly, females scored visibly better on the in-game pen design task than males. This result indicates equal appeal of the game to both genders. More importantly, however, the average player performance was above that based on a random chance, indicating that some level of understanding and knowledge transfer is effectively taking place.

Collected information provides an interesting view of the users' experiences (and hence hints for the successful game design). A surprisingly large number of visitors, nearly half (48.2%), played the game to completion (defined as any stage from the score screen until the credits) [18, 19]. This is quite an achievement for a game placed on the floor of a busy science museum. Even so, it is an examination of the 'early quitters' that really provides some interesting insights into the game. For example, the largest spike of users abandoning the game before completion occurs at the final stage of three screens of text-based instructions, 'intro_marketing_3', near the beginning of the game. A likely hypothesis is that the users who chose to quit at this point did so because the interactive task, as described to them by the instructional screens, did not seem appealing.

A correlation check across the game scores (see Table 1), time spent playing the game, and the number of clues discovered and utilized by the subjects shows that our game scoring reflects in-game behaviour appropriately (e.g. the longer the time subjects spend with the game, the more likely they are to uncover useful information and apply it to obtain higher scores). This is an important finding, because it is quite possible to build a piece of 'educational software' that has a veneer of educational content, but whose gameplay mechanics contain nothing that intrinsically leads to deeper learning.

SUMMARY AND FUTURE WORK

All of the initial observations suggest that the exhibit has achieved its initially defined goals. Preliminary results show that among the goals of the project, motivating the visitors to engage with the game content is attained. According to anecdotal observations, there is a high rate of interest from by visitors who walked by, showing that the task of attracting visitors was successfully fulfilled as well. This will be further explored with a future observational study devoted to measuring this potential of the exhibit. Measuring the degree of learning facilitation, however, hinges on refining the existing automatically collected data, so that each game play trace reflects a single user's playing experience accurately.

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