What Are School-Age Children Learning From Hands-On Science Center Exhibits?

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Introduction

Science literacy among the general public has become a topic of growing concern in the recent years (National Science Board, 1983: Twentieth Century Fund, 1983: American Association for the Advancement of Science, 1982). The current trend toward virtual scientific and technological illiteracy – unless reversed – means that important national decisions involving science and technology will be made increasingly on the basis of ignorance and misunderstanding (National Science Foundation & U.S. Department of Education, 1980). Furthermore, we have entered an era of public participation in science that must be considered part of the "social cost of democracy" (Culliton, 1978). Over half the bills introduced in Congress involved science or technology in some degree and the establishment of the Standing Committee on Science and Technology in the House of Representatives attests to the importance of scientific and technological issues in the national political system (Miller, 1983). This lack of science literacy comes at an unfortunate time, since more decisions than ever before require at least a minimal level of science knowledge and understanding. The first director of the Museum of Science and Industry in Chicago complained that "the principles of science are not yet in the possession of the many, even though the age is essentially scientific" (Kaempffert, 1929). Since that time the situation has changed very little, although most citizens apparently want to educate themselves about complex scientific and technological issues in order "to make reasoned judgements about policy-related issues" (National Science Foundation, 1980).

Most of the learning that takes place in an individual's lifetime occurs outside the formal school setting. One study states that over 80% of the learning is not done in a traditional educational setting (Beer, 1984).

Contemporary science and technology museums offer the public an opportunity to engage in informal science learning. Unlike school, the museum setting is voluntary, open-ended, nonlinear, hands-on, and entertaining. There are no requirements, no prerequisites, no exams, no grades, and social interaction is often an important part of the experience (Ucko, 1985).

The exhibits in contemporary science museums attempt to allow the visitor to experience science. After all, science literacy can be cultivated "only from concrete observational experience" not through "verbal inculcation" for most individuals (Arons, 1983). Oppenheimer (1968) stated that "explaining science and technology without props can resemble an attempt to tell what it is like to swim without ever letting a person near water."

Most visitors are not attracted to science museums to learn facts; they come to explore new and interesting phenomena and to be entertained. However, at most science museums, there is no reason to be concerned that the visitors will leave feeling that they have not confronted enough facts. When individuals interact with an apparatus they gather a different kind of evidence than when they hear or read about something. The interactive visitor can manipulate objects, explore variables, and use the evidence obtained to reach a personal conclusion about the situation investigated (Thier and Linn, 1976).

Science museums are attempting to reach visitors of all ages. This includes some small children whose thinking is primarily sensory-motor, as well as adults who are capable of more formal mental operations.

Because of the large audiences, free-choice environments, and interactive exhibits, science centers are excellent laboratories for studying how people learn. The topics that can be fruitfully addressed in the science center laboratory range from questions that are particular to the museum enterprise itself, to general questions about learning (Feher and Diamond, 1990). Recent research ranges from the predominantly descriptive to analysis of how specific features, such as display techniques or opportunity for hands-on interaction, affect visitor behavior. These studies have had surprisingly little impact on the development of exhibits and "no reliable general theories yet exist to predict how visitors will respond to exhibit features in a variety of museum settings" (McNamara, 1990). The purpose of this research is to explore the link between conceptual understanding, free exploration of hands-on science center exhibits, and Piagetian cognitive developmental levels.

Method

The subjects for this research were 45 children between the ages of five and thirteen who were selected at random from a pool of possible subjects. The sample is representative of the population of elementary school aged children who visit a science museum.

The results of a pilot study suggested that eight Piagetian tasks could provide enough information to classify each subject into one of three groups: pre-concrete, concrete, and post-concrete operational. The eight Piagetian tasks that were administered to each subject included:

1. Conservation of number
2. Conservation of liquid amount
3. Conservation of solid amount
4. Conservation of area
5. Conservation of length
6. Conservation of volume
7. Equilibrium in the balance beam task (proportional reasoning)
8. Colored beads task (combinatorial logic).

The first five tasks were used to separate the pre-concrete subjects from the concrete operational subjects, while the last three tasks served to separate the concrete operational subjects from the post-concrete operational subjects.

Subjects who did not conserve on two or more of the first five tasks were classified in the pre-concrete group. Additional members of this group were those who failed to conserve on one of the first five tasks and could not conserve on the volume task.

To qualify for the post-concrete group the subject had to be IIIA (early formal) on at least one of the last three tasks, (conservation of volume, balance beam and colored beads task) and be IIA (concrete) on IIB (late concrete/transitional) on the remaining two of the last three tasks. The subjects who did not qualify for the pre- or post-concrete operational groups were classified as concrete operational. Twelve subjects were classified as pre-concrete, 16 subjects as concrete, and 17 subjects as post-concrete.

The pilot study provided background for preparing the research design. When asked a pretest question to assess their conceptual understanding of a formal concept presented by an exhibit, 96% of the subjects had no initial understanding of the concept. The pretest question also had no impact as an advance organizer. Based on the results of the pilot study, it did not appear necessary to administer a pretest when subjects explored an exhibit that presented a formal concept.

For an exhibit which presented a concrete concept, a pretest question was administered to half of the subjects, while the other half were not asked any pretest questions. The pretest question was asked verbally with each subject's response recorded on audio tape. Additional follow-up questions were asked to further explore the subjects' conceptual knowledge. The questions were the same for subjects in all three groups.

After the pretest was completed, each subject was given time for individual free exploration of one exhibit. The exhibits included in this research are currently or have been on the main exhibit floor. All text that had been written for the exhibits remained and the written directions for use were the same ones provided for the public. No help was provided by anyone, as this was to be strictly a free exploration. The instructions were to "play with the exhibit and find out all that you can about it."

After the subjects had completed as much exploration as they deemed necessary, they were asked to explain how they thought the exhibit worked. Additional questions were asked which followed-up on the children's answers to further explore their understanding of the concept presented by the exhibit. All of the posttest conversations were recorded on audio tape. This procedure was repeated for each exhibit used in this research.

The entire dialogue between each subject and the researcher was recorded on audio tape and transcribed. The answers of each subject were compared with a concept statement for each exhibit. Data from the pilot study indicated that the answers could be classified adequately into one of four categories:

1. Complete understanding (answer closely matched the concept statement);
2. Partial understanding (answer had some elements of the concept statement, but was not complete);
3. Misconceptions (the answer contained conceptually incorrect statements);
4. No understanding (the subject stated they did not know the answer or the answer they gave had nothing to do with the exhibit.)

Preliminary analysis involved using descriptive statistical techniques. Percentages and frequencies were calculated to determine trends.

A scoring system was used to evaluate the answers of the subjects. The scoring scale was: four points for a complete answer; three points for a partial answer; two points for a misconception; and, one point for no understanding. This allowed for a statistical comparison of answers among intellectual development groups for individual exhibits.

The five exhibits chosen for this research were the *Pipes of Pan*, *Hot Air Balloon*, *Body Resistance*, *Bernoulli's Principle Airfoil Lift*, and *Jacob's Ladder*. The *Pipes of Pan* exhibit deals with the concept that longer tubes produce sounds that are lower in frequency when compared with shorter tubes of identical diameter and material. The *Hot Air Balloon* exhibit makes use of the concept that flames produce heat which in turn heats the air above the flames, which rises into the balloon and eventually causes the balloon to rise. To understand the concepts for both of these exhibits requires the use of concrete thought.

The *Body Resistance*, *Bernoulli's Principle Airfoil Lift*, and *Jacob's Ladder* exhibits deal with concepts that require formal thought. The *Body Resistance* exhibit requires that the visitor touch each of two plates to determine what resistance his/her body has to the flow of electricity. A resistance gauge on the exhibit shows that the body has a natural resistance which is neither zero nor infinity. *Jacob's Ladder* features a spark that is produced between two brass bars by a high voltage generator when a visitor presses a button. The spark moves vertically between the bars until it reaches the top. At the top the spark forms an arrow point leading from the end of each bar to a higher point between the bars. The ionization of the air around the spark causes the air under the spark to become less dense, which pushes the spark upward between the rods. The *Bernoulli's Principle Airfoil Lift* exhibit makes use of the concept that air blowing past the airfoil produces lift. Air passing over the top of the air foil moves faster than the air below the air foil resulting in lower pressure above the air foil and upward movement.

Results for Exhibits Requiring Concrete Thought

Pretest questions relating to the concrete operational thought exhibits were administered to half of the sample to determine if the pretest questions acted as advance organizers. Data for both exhibits requiring concrete thought were analyzed with 2-way ANOVAs, with main effects for the pretest and developmental level. Table 1 summarizes the percentage of subjects meeting the criteria of understanding for each of the three groups.

Table 1
Understanding of Exhibits Requiring Concrete Thought

Exhibit	Understanding	Pre-Concrete	Concrete	Post-Concrete
Pipes	Complete	75.0%	100.0%	100.0%
of	Partial	8.3	0	0
Pan	None	16.7	0	0
	Misconception	0	0	0
Hot	Complete	41.7	87.5	100.0
Air	Partial	41.7	12.5	0
Balloon	None	8.3	0	0
	Misconception	8.3	0	0

Pipes of Pan

The pre-concrete subjects' experience with the *Pipes of Pan* exhibit resulted in most of the subjects demonstrating partial or complete understanding of the concept that longer pipes produce lower sound and shorter pipes produce higher sounds. For the concrete and post-concrete groups, all of the subjects demonstrated complete understanding of the concept.

The analysis of variance results indicate significant main effects for both the presence of pretesting [$F(1,39) = 4.49$; $p = .0405$] and for developmental level [$F(2,39) = 6.48$; $p = .0037$], as well as for the interaction between the two [$F(2,39) = 4.02$; $p = .0259$]. A Ryan's test for individual comparisons revealed that both the concrete and post-concrete developmental groups had higher mean scores than the pre-concrete group.

The group that received the pretest actually had a *lower* mean score (3.71) than did the group that was not pretested (3.96). Inspection of cell means revealed that the pretest mean effect and the interaction were confined to the pre-concrete group, as the subjects in the concrete and post-concrete groups all had scores of 4.0 regardless of whether or not they were pretested. However, in the pre-concrete developmental group, those who received the pretest had an average score of 2.80, while the mean for those who were not pretested was 3.86.

Hot Air Balloon

The *Hot Air Balloon* exhibit required concrete thought to understand the concept that fire produces heat, and then the heat rises and fills the balloon, causing it to rise. The majority of the concrete (87.5%) and post-concrete developmental groups (100.0%) attained complete understanding of the concept involved in this exhibit. However, less than half of the pre-concrete subjects achieved complete understanding, although over 80% left the exhibit with complete or partial understanding.

There was a significant difference among developmental levels on understanding of the concept taught by the *Hot Air Balloon* exhibit [$F(2,39) = 10.04$; $p = .0003$]. Again, a Ryan's test for individual comparisons indicated that concrete and post-concrete groups had higher mean scores than did the pre-concrete group. There were no significant pretest or interaction effects.

Results for Exhibits Requiring Formal Thought

Bernoulli's Principle

For the exhibit titled *Bernoulli's Principle*, the majority of all subjects (regardless of developmental level) demonstrated no understanding or had misconceptions after they interacted with the exhibit (See Table 2). The entire concrete group (100%) developed misconceptions. A small percentage of the post-concrete group developed complete or partial understanding.

Further discussion with the subjects demonstrating partial or complete understanding indicated that the exhibit had no influence in their understanding of Bernoulli's principle. In fact, each of these subjects turned away from the exhibit when trying to explain Bernoulli's principle, perhaps in an attempt to keep their current experience from interfering with some past knowledge they had acquired.

Analysis of variance with Ryan's individual comparison test revealed that pre-concrete subjects again had the lowest mean understanding scores [F(2,42) = 6.16; p = .0047].

Table 2
Understanding of Exhibits Requiring Formal Thought

Exhibit	Understanding	Pre-Concrete	Concrete	Post-Concrete
Bernoulli Principle	Complete	0%	0%	5.9%
	Partial	0	0	11.8
	None	41.7	0	5.9
	Misconception	58.3	100.0	76.5
Jacob's Ladder	Complete	0	0	0
	Partial	0	0	0
	None	33.3	12.5	41.2
	Misconception	66.7	87.5	58.8
Body Resist-ance	Complete	0	0	0
	Partial	0	12.5	17.7
	None	50.0	6.3	23.5
	Misconception	50.0	81.3	58.8

Jacob's Ladder

For the *Jacob's Ladder* exhibit, all subjects developed misconceptions or demonstrated no understanding of the concept involved in the exhibit (Table 2). The majority of each developmental group demonstrated misconceptions (range from 58.8 to 87.5% for the three groups), while the rest indicated no understanding. The no understanding percentages for the pre-concrete and post-concrete were much higher than for the concrete because more of the subjects in these two groups were willing to admit they really did not understand the concept behind the exhibit. The concrete subjects would attempt to develop an explanation which was usually classified as a misconception.

The analysis of variance results revealed no significant differences among the developmental levels on their understanding scores [F(2,42) = 1.63; p = .2095].

Body Resistance

For the *Body Resistance* exhibit none of the subjects demonstrated complete understanding, however a small percentage of the concrete and post-concrete groups demonstrated partial understanding (12.5% and 17.7%, respectively). The concrete group again had the highest percentage of subjects developing misconceptions (81.3%) compared with 50.0% for the Pre-Concrete group and 58.8% for the Post-Concrete group. There were significant differences among the group's mean understanding scores [F(2,42) = 3.72; p = .0332]. The concrete and post-concrete groups had higher means than did the pre-concrete developmental group.

Comparison of Exhibits Requiring Concrete or Formal Thought

Table 3 displays the outcome of subjects' experiences with exhibits requiring concrete thought compared to those requiring formal thought. Nearly 90% of the experiences with exhibits requiring concrete operational reasoning resulted in complete understanding, in contrast to less than 1% of the interactions the exhibits requiring formal thought. Indeed, the majority of interactions (71.9%) with exhibits requiring formal thought resulted in misconceptions.

Table 3
Comparison of Concrete & Formal Thought

Understanding	Concrete	Formal
Complete	86.9	0.8
Partial	8.9	5.2
None	3.3	22.2
Misconception	1.1	71.9

A difference score was computed by subtracting each subject's mean understanding score for exhibits requiring formal thought from their mean score for exhibits requiring concrete operational reasoning. A one-sample t-test was then computed, which indicated a significant difference between the overall understanding of concrete and formal concept [t = 20.06; p = .0001]. There were no significant differences among developmental levels on this computed score.

Discussion

The level of conceptual understanding on the exhibits requiring concrete thought increased with each developmental group. The pre-concrete subjects demonstrated the least understanding while the post-concrete group had the highest level of understanding. This finding is consistent with Piagetian developmental theory. Each subject in the pre-concrete group held on to the vestiges of pre-operational thought in at least one or more of the conservation tasks initially used to determine developmental level. This contributed to their having less understanding of the exhibits requiring concrete thought than did the other developmental groups.

For the exhibits requiring formal thought to understand the concept, all groups of subjects had difficulty developing conceptual understanding. The results indicate that museum visitors who are incapable of using formal thought will develop no understanding or acquire misconceptions from an exhibit that requires formal thought. There were a few subjects who developed partial or complete understanding for two of the three exhibits requiring formal thought. The exhibits were *Bernoulli's Principle* and *Body Resistance*. It is possible that some of this could be due to prior knowledge. A subject who had extensive experience with airplanes would have a greater chance of demonstrating at least partial understanding of the concept. Airplanes are not an uncommon interest of the curious upper elementary student. The *Body Resistance* exhibit also uses some knowledge that an upper elementary student could obtain from experience with electricity and circuits. However, very few upper elementary students would have experience working with high voltage sparks. This helps to explain why no subjects had partial or complete understanding of the concept from the *Jacob's Ladder* exhibit. This could also explain why this exhibit had the highest percentage of no understanding.

Implications

For museums, exhibit planners must decide if they are trying to deliver conceptual understanding to elementary school children and others using concrete thought. If this is a goal, then exhibits will have to be designed with the learner taken into consideration. This does not mean that exhibits should provide conceptual understanding only on the concrete reasoning level, but at least some aspect of the exhibit should provide for conceptual understanding on that level.

Many schools plan field trips to science museums under the guise of educational experiences. A brief inventory of the concepts presented by the exhibits can tell the teacher whether the children will have the opportunity to develop conceptual understanding or misconceptions. If the exhibits require formal thought to understand the concepts, elementary school children either will have no conceptual understanding or they will very likely develop misconceptions.

References

American Association for the Advancement of Science. (1982). *Education in the sciences: A developing crisis.* Washington, D.C.

Arons, J. D. (1983). Achieving wider scientific literacy. *Daedalus, 112*, 91-122.

Beer, V. (1984). Testing the applicability of a school curriculum model in a non-school environment. *ERIC Educational Document* (ED244858). (Paper presented at AERA, 1984).

Culliton, B. J. (1978). Science's restive public. *Daedalus, 107*, 147-156.

Feher, E. & Diamond, J. (1990). What research says about learning in science museums: Science centers as research laboratories. *ASTC Newsletter, 18*(1), 7-8.

Kaempffert, W. (1929). The Museum of Science and Industry founded by Julius Rosenwald: An institution to reveal the technical ascent of man. *The Scientific Monthly, 28*, 481-498.

McNamara, P. A. (1990). What research says about learning in science museums: Trying it out. *Journal of Museum Education, 15*(1), 20-21.

Miller, J. D. (1983). Science literacy: A conceptual and empirical review. *Daedalus, 112*, 29-48.

National Science Board. (1983). *Educating Americans for the 21st century.* National Science Board Commission on Precollege Education in Mathematics, Science, and Technology, CPCE-NSF-03.

National Science Foundation. (1980). *Science and technology: Annual report to Congress.* NSF 80-21.

National Science Foundation & U.S. Department of Education. (1980). *Science and engineering education for the 1980s and beyond.* Washington, DC.

Oppenheimer, F. (1968). A rationale for a science museum. *Curator, 11*(3), 206-209.

Thier, H. D. & Linn, M. C. (1976). The value of interactive learning experiences. *Curator, 19*(3), 233-245.

Twentieth Century Fund. (1983). *Report of the Twentieth Century Fund Task Force on federal elementary and secondary education policy.* New York.

Ucko, D. A. (1985). Science literacy and science museum exhibits. *Curator, 29*(4), 287-300.