THE MASTODON MATRIX PROJECT: AN EXPERIMENT WITH LARGE-SCALE PUBLIC COLLABORATION IN PALEONTOLOGICAL RESEARCH

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ABSTRACT

An important long-term goal of science education reform is to involve more students in open-ended inquiry and authentic research. In making such "research partnerships" between scientists and students commonplace, it is critical to determine how to attract willing participation of a large number and variety of classrooms while achieving genuine scientific goals. Since early 2000, the Paleontological Research Institution and Cornell University have been administering a research partnership involving non-specialists in collecting and sorting fossils from sediments collected around recently excavated mastodon skeletons. This research partnership quickly drew a diversity of participants from across the country. Feedback on participation in this project has been extremely positive, and student discovery has yielded a large reference collection of small fossils that otherwise may not have been recovered.

Based on feedback in surveys and letters, oral discussion, and other observations, we surmise that this project is popular because of the mystique of large vertebrates and because of the knowledge that this project is "authentic." Ability for non-specialists to participate is enhanced because the activity is simple to undertake, requires little equipment, is intellectually straightforward, and is open-ended enough to readily adapt to other curricular goals.

Keywords: education – precollege; education – special clientele; education – geoscience; paleontology (general); surficial geology – Quaternary geology

INTRODUCTION

Within the past decade, it has become widely recognized that it is important to involve students and their teachers in open-ended scientific research, particularly in connection with inquiry-based approaches as promoted by the National Research Council (NRC, 1996) and the AAAS (1989). "Research partnerships" involve non-specialists in helping carry out scientific research. Such partnerships are potentially a significant "win-win" experience for all stakeholders: non- specialists such as K-12 students or others gain experience in authentic inquiry, and scientists pursue research that might otherwise be prohibitive due to significant human resources necessary to collect data. Some research partnerships, such as GLOBE (Rock et al., 1997) and Project FeederWatch (Bonney and Dhondt, 1997) have reached national and international audiences. These remarkably popular and successful programs reach hundreds of thousands of students each year and provide a model of the potential for research partnerships; as many students as these programs engage, however, they still reach only a small percentage of the student population in a given year.

Thus, one of the major challenges facing science education reform is how to make research partnerships between students and scientists sufficiently widespread to become a typical experience during the school years of most students, and thus to have an impact on science education nationally (Ross and Harnik, 2003; Harnik and Ross, 2003a). It is important to examine the potential hurdles to widespread creation of research partnerships, and to consider what kinds of research may lend themselves more readily to willing involvement of large numbers of non-specialist individuals. Through a fortunate, but unplanned, opportunity, a research partnership emerged at the Paleontological Research Institution (PRI) that has enabled us to examine some of these issues in greater detail.

In January 2000, an informal research partnership was created through a sudden need for human resources to scour sediments for fossils from the excavation of a late Pleistocene mastodon skeleton. The "Mastodon Project" was a joint effort between PRI and the Department of Earth and Atmospheric Sciences at Cornell University. Largely through media reports and word of mouth, the partnership project grew to involve tens of thousands of participants of a vast variety of backgrounds, most of them school-age children, within just months of its inception. Despite interest by PRI education staff in careful formative evaluation of research partnerships (e.g., Harnik and Ross, 2003b; Lawrence et al., 2001, Lawrence, 2001), the nature of the project's origin resulted in less structure to the exercise, outside of basic instructions for sorting the matrix, than we would have otherwise preferred. Beyond research goals, the project has thus led to an experiment on the attitudes and educational experiences of large numbers of participants engaged in relatively unconstrained scientific discovery. Specifically, we have begun to explore what factors caused this project to expand so far beyond our expectations, in order to better understand how these factors might be used to strengthen research partnerships more generally.

Figure 1. Student sorting through Chemung mastodon matrix. The coarse material being sorted is largely a comination of small shale pebbles and spruce twigs.

Figure 2. Class of students sorting through Chemung mastodon matrix, with PRI geologist Peter Nester in the background. Each separated component is put on a separate plate or coffee filter. The cups hold muddy sediment.

MASTODON DISCOVERY IN CHEMUNG COUNTY, NEW YORK

In the fall of 1999, a pond in rural Chemung County, New York, was being deepened, and large bones were discovered. A team from Cornell University excavated the site for about 3 months, recovering more than 300 bones. What became known as the "Cornell mastodon" is in fact about 65% of a mastodon and about 25% of a mammoth (the first time that mammoth and mastodon remains have been found in the same place from sediments of the same geological age in New York State) (Allmon et al., 2001). The skeletal material was moved to the Paleontological Research Institution in December 1999 for storage, curation, preparation, and public exhibit.

The circumstances of the excavation were such that there was little time for careful sieving of the sediment on site, and so initially a modest quantity of buckets of matrix were collected for washing and screening in the lab. As winter approached and snow began to fall, sediment was removed as a dump truck load of matrix (approximately 10,000 kg), scooped up at the site and deposited in a backyard near Ithaca. This matrix, including both peat and underlying organic-rich marl, is very fossil-rich and contains abundant wood, shells of freshwater mollusks, bone fragments, and an extensive variety of other fossils. Although the material was not collected in a stratigraphically-constrained manner, and so could not be used to address certain questions (such as how, in detail, environments changed before and during the life of the mastodon), inventorying these remains guaranteed that small fragments of mastodon bone would not be lost. Inventorying other fossils also promised: (1), to provide general information on reconstruction of the late Pleistocene environment in and around the pond, and, (2), creation of reference collections for paleontologists studying the systematics and paleobiogeography of Quaternary fossil groups.

There was considerable media coverage of the excavation, as is common with large fossil vertebrates, and it was through the media that what we have come to call the Mastodon Matrix Project was initiated. Once the bones and sediment were onsite in Ithaca, Chiment made an offhand suggestion to a reporter that in principle it might be possible for classes of students to help with the enormous job of inventorying materials in the matrix. Within 24 hours a dozen requests for matrix samples had been received from teachers. We bagged up a few 2.2 kilogram (5 pound) samples and gave them out with informal instructions for processing, and requests continued to arrive. The media became especially attracted to this aspect of the project, which connected researchers to school children and others in the general public, and more coverage generated more requests.

Sorting of this matrix became an important component of the overall research project, since large numbers of participants could potentially process large amounts of matrix in a relatively short period of time. Specifically, participants in the "mud project" were able to separate several categories of materials from their samples that were potentially of great utility for a variety of ongoing research areas, and could provide the basis for a growing database on materials associated with the mastodons themselves. These categories include in particular: 1) plant macrofossils, 2) other vertebrates, 3) beetle parts, and 4) pebbles. Numerous eyes sifting carefully through the matrix potentially provided a far greater amount of material for study than could have been generated by the available staff.

Though it was not initiated as a formal educational activity, we soon recognized that such an experience could expose students to the excitement of scientific research and the kinds of materials scientists use to reconstruct the past. Since such a large amount of material was collected, loss of some material, instances of low-effort, and inaccuracy of some data were considered reasonable risks given the potential returns. Many of the materials students discovered in the matrix are very similar to natural objects that can be found in their own neighborhoods (e.g., twigs, leaves, and rocks), making the project materials familiar and interpretable. Knowing that these twigs and stones were found associated with the bones of Ice Age proboscideans, however, made the ordinary extraordinary.

Within 6 months, we had received and filled almost 2,000 requests for samples, and a system was set up for distributing 2.2 kilogram bags of sediment. The instructions were improved (but kept brief), asking participants to sort and weigh various components, and then return the organic components and data to Cornell

Group Size	
	Individuals: 1 person
	Small: 2-20 people
	Medium: 21-50 people
	Large: 51-100 people
	Very Large: 101-500 people
Participant Localities	
	Rural: <10,000
	Small Town: 10,000-50,000
	Town: 50,000-100,000
	Small City: 100,000-200,000
	Urban: >200,000
Participant Group	
	Public or Private School
	Home School
	Family Project
	Youth Group (Boy or Girl Scouts, etc.)
	Independent Study-hobby
	Independent Study-professional
	Public Service (wide variety of other groups)
Age Group	
	Preschool
	Elementary
	Middle School
	High School
	Adult
	Mixed Ages

Table 1. Descriptors of participant groups.

or PRI (a version of the instructions can be found at www.geo.cornell.edu/mastodon/Bag/instructions.html). Requests came mostly from teachers in formal classroom settings, grades K-12. Samples were sent to school classes in 49 of 50 states (Hawaii being the exception) and 4 foreign countries. In addition, non-classroom groups such as prisoners, nuns, senior citizens, handicapped persons, home schoolers, and other community groups became involved in the project. In total as many as 50,000 individuals may have participated in the project (Figures 1, 2). A public exhibit documenting both the process and products of this public involvement was set up at PRI, adjacent to a publicly visible preparation laboratory for mastodon skeleton display; the entire research project has been described in an evolving website (see www.priweb.org/mastodon/mastodon_home.html[the "Gilbert/Cornell" mastodon is equivalent to the "Chemung" mastodon] and www.geo.cornell.edu/mastodon/).

RESULTS: COLLECTION OF DATA ON RETURNED SAMPLES

As of February 2002, more than 400 of the 2000 bags had been returned, a return rate of approximately 20%. Given the range of group sizes that participated, an estimated 7000-7500 individual participants studied the samples that were returned (many more may have worked with materials that were not returned). The public's participation in the matrix sorting quickly provided a preliminary paleontological and sedimentological inventory of the Chemung site. Such materials then provide a basis for further research. Materials sorted and returned in these samples included: mastodon bone fragments, bones of other taxa such as muskrat and frog, feathers, large quantities of twigs, leaves, seeds and wood representing more than 20 species of plants, freshwater clams and snails, beetle parts, and fibers that may be mastodon hairs. Some of these materials were then examined by partnering specialists.

RESULTS: FEEDBACK ON EDUCATIONAL OUTCOMES

Public reception of the project has been extraordinary. We have received numerous enthusiastic testimonials of student excitement for participating in matrix research. For example, a teacher from Oklahoma wrote, "Our students are wildly enthusiastic about this mastodon matrix! They keep saying, 'How cool!' and 'Why are those scientists trusting us with this important work?' What a marvelous experience!" Project staff were asked to give presentations at many local (Central New York) schools that had participated in the project. Of those who returned materials, 86 completed a survey about their experience. Nearly all of these, 93%, expressed interest in participating in similar projects in the future. For example, a teacher from a children's home in Pennsylvania wrote, "These experiments helped Mr. Day's students realize that learning can be fun and rewarding; they were very enthused about the project. In fact, they had such a good time that our students and teachers have expressed interest in participating in subsequent projects. Again, thank you for allowing so many others to expand their imaginations and knowledge by sharing in the excitement and discovery of this fascinating project." Another from a rural elementary school in New York wrote, "We want to thank you for giving us this exciting opportunity to work like real paleontologists on a dig...The science room rang with squeals of 'I found a twig,' 'Here's a hair,' and 'This stone looks like a tooth.' We would love to participate in any future activities you could provide for us. It has been a wonderful learning experience for our entire school."

We have received hundreds of letters, drawings, photographs, and other materials returned with specimens extracted from the mud. While most classes appear to have spent a few hours over a day or two on it, some teachers made it the focus of a whole unit or even, in one case, an entire semester.

All of this positive feedback must be examined, however, against the fact that over 70% of the samples have not yet been returned. Further, some of the samples that were returned, even those by participants reporting a positive experience, were missing certain, sometimes many, components of the sample or the data. Acquiring data on why participants did not return their samples is, by its nature, more difficult than understanding who did complete their work, and will require substantial human resources to investigate. Rate of receipt of returned data and samples has only recently slowed enough to consider this phase to be coming to a close, thus exploration of non-returns is planned for the future.

Size of Community	Rural	Small Town	Town	Small City	Urban			Total
Number of Groups	202	119	13	17	18			369
Group Size	**Single**	**Small**	**Medium**	**Large**	**Very Large**			**Total**
Number of Groups	25	148	87	18	7			285
Group Type	**School Class**	**Home School**	**Family Project**	**Youth Group**	**Individual: Hobby**	**Individual: Professional**	**Public Service**	**Total**
Number of Groups	252	8	33	9	23	4	26	355
Age of Participants	**Preschool**	**Elementary School**	**Middle School**	**High School**	**Adult**	**Mixed Ages**		**Total**
Number of Groups	4	114	68	64	24	42		317

Table 2. Participant groups in terms of where they live, how big they are, what kind of group they are, and what the age group is. Totals are not equal because information was not available for every group in every variable.

Size of Community	Rual	Small Town	Town	Small City	Urban			Total
Achieving Request	97 (48%)	63 (53%)	7 (43%)	13 (76%)	7 (39%)			187 (51%)
Group Size	**Single**	**Small**	**Medium**	**Large**	**Very Large**			**Total**
Achieving Request	11 (44%)	75 (51%)	51 (59%)	13 (72%)	6 (86%)			156 (55%)
Group Type	**School Class**	**Home School**	**Family Project**	**Youth Group**	**Individual: Hobby**	**Individual: Professional**	**Public Service**	**Total**
Achieving Request	139 (55%)	5 (63%)	14 (42%)	5 (56%)	7 (30%	4 (100%)	8 (31%)	182 (51%)
Age of Participants	**Preschool**	**Elementary School**	**Middle School**	**High School**	**Adult**	**Mixed**		**Total**
Achieving Request	2 (50%)	53 (46%)	42 (62%)	32 (50%)	9 (38%)	27 (63%)		165 (52%)

Table 3. Number of participant groups that met or exceeded expectations in materials and data returned, and percentage of total participant groups that returned materials. Totals are not equivalent because information was not available for every group on every variable.

RESULTS: DEMOGRAPHIC DISTRIBUTION OF PARTICIPATION

After collecting returns, a database was created that organized all participant groups according to four characteristics: (1), size of group, (2), demographics of locations of participant groups, (3), type of participant group, and (4), age group (see Table 1 for description of these groups). These statistics enabled us to examine in more detail which groups had selected to participate in this kind of research experience. In examining these data, an important caveat is that we do not know in detail in what ways media publicity about the project may have been biased toward and against certain audiences. We do know that a large number of participants were from the Central New York area around Ithaca, which is a rural area.

Participants in the project ranged from preschool to adults, from families to professional paleontologists, from individuals to groups of over 100, and from rural to urban. Certain types of participant groups were, however, much more common than others. The modal participant in this project was an elementary school class from a small town. Table 2 summarizes the most basic demographic data; the following observations summarize the findings. For these purposes each group of any size is counted as one participant group.

Over one half of all participant groups were small and middle-sized groups *at schools*. About one third of all samples were given to small and middle-sized groups of *elementary* school children; and another one third were given to small and middle-sized groups of *middle school and high school* students. Over 85% of participant groups that were middle-sized, large, and very large groups were at elementary schools.

Small and medium sized groups (schools and otherwise) from *rural and small town settings* account for over 70% of the total groups. All together rural and small town samples accounted for more than 85% of the total participant groups.

Among the fairly small number of individual people participating as a participant "group," over 40% were adults and over 50% were "hobbyists" (hobbyists were not all adults, nor were all adults hobbyists). Families accounted for about 20% of small participant groups, and were 9% of the total participant groups.

RESULTS: MEASURE OF PARTICIPANT EFFORT

A subjective internal scoring of returned work was used as a very rough proxy of apparent participant effort. We assume that the more interested or engaged participants were, the more effort they likely expended on the project, which would be reflected in whether all the materials were sent back with the data sheets filled out completely, and whether the participants went beyond the minimum activities suggested to create other educational materials (which we asked to hear about). Participants who returned all the most basic requests were ranked as "good," while those participants who undertook additional data analysis and/or provided additional educational experiences received "very good" or "excellent" scores. These scores were not shared with participants, nor was any mention made of a scoring system. Age-level was not consciously taken into account, thus scores are not intended to take into account any a priori expectations of the quality of received work. Results are shown in Table 3.

As the group size increases the *likelihood* of greater effort increases: from smaller to larger groups, the percentages receiving positive effort scores grow monotonically from 44%, 51%, 59%, 72%, to 86%. Groups that may on average have more coherent educational goals — schools, youth groups, and home schoolers — are more likely to have shown effort (55-63%) than those that may on average have less formal educational goals, such as families, individual hobbyists, and public service groups (30-42%).

Middle school groups had somewhat more frequent positive effort scores (62%), but there is not a great deal of difference between different age groups ranging from pre-school to high school (47%-62%). Interestingly, adults scored the lowest (38%), due apparently to the relatively low number of positive effort scores received by hobbyists. The small sample of participants from small cities had a relatively high number of positive effort scores (77%), while all other settings (rural, small towns, towns, urban) showed a more moderate frequency of effort (39-52%).

EVALUATION AND DISCUSSION

Why was the mastodon matrix project adopted so quickly by so many? - Soon after the Mastodon Matrix Project began, the rate of requests to participate in the mastodon matrix project grew to a level that stretched the human resources that the Mastodon Project could devote, even with the help of a dedicated team of volunteers. Requests for matrix soon outstripped quantity of material available, and we had to turn down many potential participants; most of these requesters opted to have their names added to a list to participate in a matrix project from the next matrix excavation (the Hyde Park project, described below). It took almost no effort to find willing participants. Even with the limited efforts we were able to devote to the project, most of those returning evaluation forms reported positive experiences. If the reasons for the enthusiasm for this project can be understood and integrated into other research partnerships, it could have a major impact on the development and scaling up of research partnerships generally.

Our primary reference for understanding participants' reactions is qualitative data from group leaders who filled out a project evaluation form. This is added to our personal observations of participants working with matrix in classroom outreach programs and museum-based family activity days at PRI (Rigas et al., 2000). We also have anecdotal reports ranging from discussions with group leaders who have participated, to the many instances in which we have come into contact with parents whose children were involved in a school matrix project.

Our observations might, in hindsight, have been expected, but they are validated by the actual experience. The first two involve intrinsic interest in, and commitment to, the topic of the research partnership:

1) There is a mystique to megavertebrate fossils that made the project compelling. Dinosaurs, for example, have become a common hook for teaching the principles of science in classrooms from kindergarten to college, and are used in a wide variety of educational media from documentaries to museum exhibits to children's books (e.g., Glut, 1980; Mitchell, 1998; Silverberg, 1992; Dodson, 1992; Stucky, 1996). Though we expect that the appeal of the mastodon excavations may be especially high in New York State, close to the site of the excavations, evidently the interest in Ice Age proboscideans is great enough to be of interest to people of distant communities (note also Disney's blockbuster animated film, *Ice Age*, released in 2002).

2) Authentic discovery and interpretation are involved. We have heard repeatedly, in a variety of circumstances, that students take the project more seriously, and are more engaged when they know that they are collecting specimens for use in real scientific research. We have found similar results with a student-scientist partnership project that involves Devonian-age invertebrates (Harnik and Ross, 2003b).

The project is also easy to undertake and understand. While fewer participants made remarks about this aspect, our experience in educational outreach has shown that practical convenience and background-appropriateness are critical to success. We surmise that the following three characteristics have also been important for ready adoption of this matrix research partnership:

3) The protocols are simple and the materials familiar even for non-specialists. Little equipment other than very simple household supplies is necessary to undertake the project. Thus there is little or no financial investment, and little investment in training, necessary to undertake and understand the project.

4) The most basic goals of the project, to use fossils to reconstruct what used to live in the area around the mastodon as the last ice sheets retreated, is straightforward to understand even for non-specialists. More refined goals, such as figuring out why certain kinds of fossils might be more common, and what might bias fossil preservation, are intellectually accessible if teachers have an interest in taking the project further. The questions students and teachers ask and attempt to answer are in this sense truly open-ended.

5) The project is sufficiently open-ended that it can be incorporated into a wide variety of contexts. Teachers can use the materials to talk about, for example, ecology, climate change, or geologic history; they can also involve students in exercises

using writing, math, and art (for example in presenting class results).

Who is most likely to be actively engaged in the mastodon matrix project? - Our experience suggests *both* that (1), willing participants in research partnerships such as the Mastodon Matrix Project potentially come from audiences of nearly any background, yet (2), certain types of audiences are considerably more frequent participants. In our particular case, elementary schools in rural towns are easily the most frequent participants. We do not have detailed information that would suggest why certain groups participated while others did not, but we can draw some inferences and implications from other available information.

Schools - It is common knowledge among museum educators that elementary school classes, particularly in New York State, have greater flexibility in their schedule than do secondary school classes. In New York this arises from the heavy content load of New York's secondary school "Regents" curriculum and assessment. Thus, unless the Matrix Project is associated with covering Regents curriculum content, it is less likely a teacher may take the necessary two or three class periods necessary for the project.

Since many of the participants are from an area surrounding the Chemung mastodon site and Ithaca, which are within a geographically extensive rural area of New York State, it is not surprising that most participant schools were rural. Participants from other parts of the country might have been less biased demographically. It is thus not clear if urban schools are relatively less likely to participate, or if the demographics of participant groups simply reflect biases of local circumstances and national media.

Other groups - The most significant point that might be drawn about group participation is that such a variety of groups requested to participate. At a time when there is much concern about interest in and knowledge of science by the general public (NRC, 1996), these observations reconfirm that certain topics such as ancient life rekindle curiosity that transcends differences in age and educational level.

Is the mastodon matrix project a "research partnership"? - An ideal student-scientist partnership, as defined by Barstow (1996), involves students collecting data that will be used in published scientific research and enables the students to ask their own questions of the data set. This project meets these criteria, but in a less direct manner than some research partnerships.

If collecting conditions had been better, samples would have been carefully collected stratigraphically, and data from students would have helped document temporal changes in environment (as in the Devonian Seas project [Harnik and Ross, 2000]) and helped reconstruct the environment in detail at one point in time (such as during the life of the mastodon). The field conditions, however, made this unfeasible. Unusual pressures to finish the Chemung excavation meant little time to counteract slumping and mixing of unconsolidated muds, greatly reducing the stratigraphic resolution of individual buckets of sediment. Moreover, the withdrawal of mud on the final day of field work mixed the entire section of peat and marl around the skeleton, representing what may have been hundreds (or even thousands) of years of deposition.

The fossils contained within the mud can be used, however, for other kinds of scientific work, such as studies of the systematics and biogeographic distribution of the individual organisms preserved in the section. These fossils are being stored in the PRI research collections. Such museum collections are valuable for scientific research by, for example, paleontologists and organismic biologists. They exist as *archives* of nature and are not always made with specific scientific questions in mind. In some circumstances, such as in the case of the mastodon matrix, collection occurs to avoid permanent loss of a potentially important part of the fossil record. Publishable scientific work, and the full spectrum of scientific processes, may not be occurring at the time the students are helping create the collections.

In the case of the Chemung Mastodon Matrix Project, the primary role of the students was to find and sort fossil components, to create reference collections of both common specimens and rarer material (e.g., small bones) that would not otherwise have been known from the site, and to document relative abundance of selected components. These will be used in collections-based research that may occur within the current Chemung research program or at some point in the future.

Is the mastodon matrix project of educational value? There is substantial anecdotal evidence that teachers and students *like* participating in the matrix project, and the fact that the vast majority of teachers who responded in evaluations would like to do another similar project is strong support for the supposition that the project is of educational value from the perspective of group leaders. Our assumption in this particular kind of research partnership is that some educational value is intrinsic to the experience of working with the matrix, while full educational value is dependent upon the teacher providing context to make the project meaningful. What is common to and striking about many teacher comments is mention of (1), the sense of discovery that many students feel and, (2), the value the students feel in being entrusted with authentic research material. Teachers apparently assume, without necessarily saying so explicitly, that such experiences are important for their students' education. The student enthusiasm and experience with the process of discovery to which teachers refer is less about scientific content, and primarily about affective variables, such as student attitudes toward science. It is widely believed (though difficult to document rigorously) that if students believe science is exciting and accessible, they may be more engaged in learning in their school science classes, and are more likely to see science as a potential career (e.g., Simpson et al., 1994). We would like to believe in addition that the process of doing the project leads to a useful experience with collaborative work and open-ended inquiry about the fossil materials that are recovered. Student experiences in this regard must depend highly on the approach of individual teachers and group leaders.

There are, of course, many additional layers of potential educational impact, ranging from understanding the process of research on fossil materials to increased awareness and understanding of climate and environmental change and extinction. Some of this content is provided at a Website for the general public, which has a written log of the excavation, updates on research, photographs, and other information (www.priweb.org/mastodon/mastodon_home.html).

MORE MASTODONS: HYDE PARK AND NORTH JAVA, NEW YORK

In the fall of 1999 a second mastodon was discovered in a pond in Dutchess County, near Poughkeepsie, NY, in the Hudson River Valley. Much of the remaining part of the skeleton was discovered and then excavated by PRI staff and volunteers and Cornell students in late summer 2000. This skeleton turned out to be one of the most complete and best preserved mastodons ever found. This discovery generated even more publicity than the Chemung County find, culminating in a one-hour Discovery Channel special (*Mastodon in Your Backyard: An Ultimate Guide*). The skeleton and site show interesting differences with those from Chemung, and a direct comparison between these two well-documented excavations is ongoing (Allmon et al., 2001). In this instance, time and weather were more cooperative, and, in addition to 10,000 kg of bulk matrix, we collected large samples from stratigraphically-constrained levels to use in research. Some of this is intended for pre-college classroom participation in research. Thus, in addition to continuing the less formal partnerships, these stratigraphically-constrained samples will enable us to work with classes on current scientific problems concerning environmental change.

In summer 2001 a third, less complete female mastodon was excavated in North Java, Wyoming County, New York, south of Rochester (Allmon et al., 2002). Matrix was again recovered from the site. Research on this site is just beginning, and current plans are for matrix from this site to be investigated through research partnerships after the Hyde Park matrix has been well studied. Natural history collections grow in value as the reference material becomes more comprehensive, thus one long-term research goal, in which students will participate, is the development of significant New York late Pleistocene lacustrine research collections.

MODIFICATION OF APPROACH BASED ON EXPERIENCE WITH CHEMUNG MATRIX PROJECT

It is easy to envision how the Matrix Project could grow substantially in number of participants, amount of associated educational materials, and amount of direct student-scientist interaction. Expanding the scale and quality of the project is in development, but it is highly contingent on available human and financial resources. Within our finite resources, we are considering modifying the protocol for the Hyde Park and Java Mastodon Projects to maximize both scientific and educational effectiveness. Several practical modifications are being made based on our experience with the Chemung project.

1) Changing student attitudes toward science arises repeatedly as one of the most valuable potential impacts of such a research partnership. Surveys that accompany the Hyde Park Mastodon Project request more explicit and quantitative data on how students reacted to and were influenced by experience with the project.

2) Instructions must be simple and clearly written, to avoid confusion and the appearance that the project is difficult. Starting with the Chemung matrix project directions, the Hyde Park matrix project instructions have been clarified and tailored to the somewhat different fossil fauna (http://www.priweb.org/mastodon/matrix_project.html).

3) Simple follow-up with participants is important to better insure that the samples are eventually investigated, and to find out in which cases samples are not used by groups that request them.

4) Observation of the data of others helps keep participants feeling they are part of the research community. PRI is in the process of creating an on-line interactive database that will eventually allow participants to enter data on-line. This same database will allow participants to see the data of other participants and receive other kinds of information about the project.

SIMILAR RESEARCH PARTNERSHIP MODELS

Research partnerships begun in order to collect large numbers of observations toward authentic scientific research have been growing in size and diversity since at least the early 1990's, as revealed by the papers in this volume, in Barstow et al. (1996), and in the development of GLOBE in the early 1990s (Fried et al., 1996; Butler and MacGregor, 2003), to name just a few examples. More generally, the goal of leveraging public interest and resources toward scientific goals has a distinguished history. For example, museum volunteer programs involving amateur fossil collectors have long been a way to increase and maintain museum paleontological research collections. Frank Chapman, an officer in the Audubon Society, started the Audubon "Christmas Bird Count" in 1900; that data has been collected by amateur birders annually ever since, and now involves over 50,000 individual participants per year (National Audubon Society, 2001). This has resulted in data that has been used in dozens in scientific publications (e.g., Raynor, 1975, Drennan, 1981, Root, 1988). Numerous scientifically important ornithological "citizen scientist" and "student-scientist" partnership projects are now run at Cornell's Laboratory of Ornithology (e.g., Bonney and Dhondt, 1997). All of these projects have in common that they began primarily as a mechanism for large-scale data collection, onto which was built the opportunity to educate public participants.

Other groups have run similar projects on matrix from mastodon and mammoth excavations. The Mammoth Park Project at Oregon State University uses an excavation as a professional development model to enhance teachers' understandings of the nature of scientific inquiry (www.orst.edu/dept/csfa). The teachers help collect the material from the excavation site, and collect and analyze the data on soils and paleoecology, including extracting fossil material with their students.

The Nova Scotia Museum of Natural History was involved in late 1991 in excavation of mastodon skeleton from a gypsum quarry (collections.iac.gc.ca/fossils/sites/mastodon/index.htm). In a situation that sounds uncannily like the Chemung Matrix Project, within 5 months of suggesting that schools could help sift through mud surrounding the bones, about 4 tons of mud was collected and shipped to about 300 schools. In addition to mollusks, wood, and other fossils typical of late Pleistocene lacustrine depositions, the students found a juvenile turtle, fish bones and teeth, a Caribou tooth, and mole and muskrat teeth, all of which became part of the Museum research collections.

SUMMARY AND CONCLUSIONS

The Mastodon Matrix Project was invented to involve volunteers in sorting through tons of sediment from a mastodon excavation to find fossil materials useful for Quaternary paleoecological and paleontological research. Within months of the announcement of matrix availability, group leaders representing tens of thousands of potential participants had notified PRI and Cornell researchers of their interest in participating. Teachers and group leaders from a wide variety of places and backgrounds recognized the project as educational and intrinsically interesting to their students. Teachers who have participated remark especially on student interest, which apparently reflects the belief that interest translates into improved attitude and learning.

The experiment has enabled us a first estimate of which kinds of groups are most likely to participate in a paleontological research partnership, and to try to understand what made this partnership so attractive to so many. The results have confirmed previous observations that both paleontology and authentic science effectively grasp student interest. Also contributing are simplicity of the protocols, familiarity of the materials, and intellectual accessibility of the issues.

The Mastodon Matrix Project was undertaken especially by elementary school classes from rural areas and towns. On average, moderate to larger groups at schools or other educational settings were somewhat more likely to have expended considerable effort on the project. There is, however, much greater variability within than between groups in effort and quality of work.

Research projects such as the Matrix Project do not meet all goals of an ideal student-scientist partnership; in particular, the scientific contribution of the students is primarily that of creating substantial long-term museum research collections of late Pleistocene fossils, rather than of solving specific scientific problems. Further, the educational value beyond the learning associated with hands-on discovery is highly dependent on the effort devoted by the group leader to provide meaningful context.

Most teachers and other groups leaders, however, have provided very positive feedback on student reaction to the project and say they would do a similar project again if the opportunity arose. Most importantly, two fundamental outcomes seem achievable from activities like the Mastodon Matrix project:

- individuals of a wide range of ages and backgrounds do get excited about science, if exposed to authentic materials, discovery, and topics of deep personal interest;
- and the scientific community can benefit from processing of considerable quantities of materials that provide new opportunities for problem solving.

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