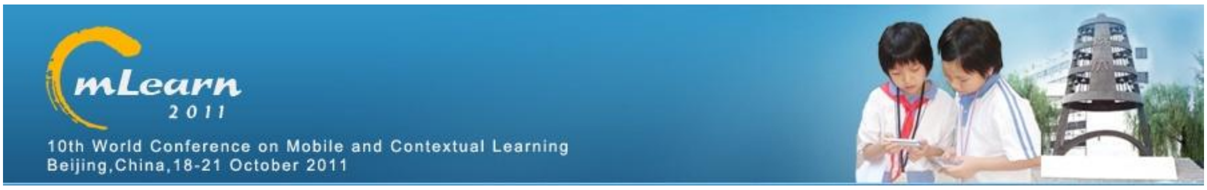

Student use of multimodal data and metadata tools during nomadic inquiry

Clara Cahill[1], Wan-Tzu Lo[1],Alex Kuhn[2], Chris Quintana[1], Brenna McNally, Shannon Schmoll[1], Joseph Krajcik[1]

[1]School of Education
University of Michigan
610 East University
Ann Arbor, MI 48109
{claracah, loclaire, quintana, schmoll, krajcik}@umich.edu

[2]Department of EECS
University of Michigan
2260 Hayward St.
Ann Arbor, MI 48109
kuhnalex@umich.edu

ABSTRACT

Museums and other informal environments offer rich opportunities for students to engage with scientific phenomena. Research suggests that connecting these informal experiences to classroom curricula through science inquiry can improve affective and learning outcomes. Zydeco is a mobile- and web-based program designed to connect classroom and informal settings through inquiry-based investigations. Classes plan and design their own investigations prior to visiting a museum. From prior knowledge, students generate sub-questions to help them complete the investigation, and potential tags that they could apply to the data they will collect in the museum. This information is uploaded to a mobile device that students use during the museum visit. In the museum, students conduct research, collecting and annotating data to pursue their investigation. Upon returning to the classroom, the students sort and analyze their data in order to complete the investigation. Zydeco provides several metacognitive and sensemaking supports to help students conduct inquiry mindfully as they collect data in the museum. Students are prompted to record an audio memo to explain the significance of each piece of data they collect. Additionally, students annotate the data using the tags they created prior to the field trip, or create new tags. This study of 85 middle-school students examines how these metacognitive and sensemaking supports were used by students during a field trip, and how each feature related to the quality of collected data and learning outcomes.

Author Keywords

Mobile learning, nomadic inquiry, informal learning, learner-centered design, bridging formal and informal learning

INTRODUCTION

Three overarching goals motivate science, technology, engineering, and mathematics (STEM) education : to create an informed and engaged citizenry capable of principled science-based personal decision-making and policy evaluation; to inspire and foster lifelong learners who have the ability, curiosity, and interest to pursue - in a self-directed manner - scientific topics; and to inspire and motivate talented students to pursue STEM careers with the ultimate goal of improving society and the world [16]. Those goals of STEM learning from national policy suggest that it is important for school knowledge to help students learn to navigate the real world. Learning in schools alone has not traditionally been sufficient to achieve these goals, as success in these three areas requires students to use and engage with scientific practices in contexts and settings outside of school [3].

Learning science research demonstrates that learners actively build new understandings on a foundation of prior knowledge and experience by applying and working with ideas [17]. Further, as Pugh and Bergin (2004) describe, "experience provides a foundation for learning and gives it meaning." The context in which students learn and develop understanding and skills is connected to their ability to apply that understanding and those skills [14]. This means that who students are learning with, where they are, what they are doing, what tools they are using, what their role are, and what the goals of the activity are all factor in to how they make sense of the world at any given time [14]. In this way, context - physical, sociocultural, and personal - is inseparable from learning. Thus bridging formal and informal learning environments – and helping students learn to apply their school-oriented practices and knowledge outside of the classroom – is essential.

Meeting the goals of STEM learning also requires engaging students in inquiry, the set of practices that drive new learning and the development of understanding in these fields [16]. Inquiry requires students to participate in iterative, complex investigations involving observation, experimentation, imagination, modeling, reasoning, collecting, analyzing, evaluating, and communicating about the phenomena under study [11]. Participation in these processes enables students to develop an experience-based understanding of the nature of science and scientific understanding alongside conceptual understanding.

Inquiry is complex, and in schools is structured, sequenced, and supported by teachers [12, 18]. Project-Based Learning (PBL) is one strategy used to engage students in meaningful inquiry in schools. PBL is based on four essential components: (a) a meaningful driving problem that drives student learning throughout the investigation, (b) collaborations among teachers, students, and the community, (c) investigations that support the development of artifacts to help students "learn content, represent information, and apply knowledge", and (d) technological support [11]. Although PBL-based learning environments can vary in terms of the amount of teacher guidance and student direction, they are designed to support students to develop inquiry skills and content understanding over time. In contrast, informal learning environments are often characterized by reduced structure, and are generally most effective at improving learning and affective outcomes when the experience is mediated by a learning agenda and guiding questions that afford students choice and control [1, 8].

Mobile technologies can provide new ways to scaffold inquiry [15]. Further, mobile technologies introduce new facets of choice and control by affording students the opportunity to collect data and make sense of their experiences in multimodal ways[21]. To this end, *nomadic inquiry* – technology-supported inquiry conducted on-the-go, across settings – must be carefully designed in order to guide and support students without limiting or controlling their experiences in the informal settings too excessively [9].

This research focuses on three supports for nomadic inquiry:

1. Enabling multimodal data collection
2. Prompting students to reflect about meaning of the data they collected through voice memos appended as metadata

3. Allowing students to annotate their data efficiently using tags

The first support, enabling multimodal data collection allows students to have choice and some control over how they wish to represent their data qualitatively. The second and third support students' metacognition and sensemaking by encouraging them to be thoughtful and reflective about the data they collect, and by providing cues to remind them of concepts they have learned previously in class. In this research, we explore how students use these supports to build new understandings and to make sense of their experience in the informal setting. Specifically, we investigate the questions:

- How do students usereflective voice memosand tags to make sense of their data?
- How do these metacognitive and sensemaking supports relate to learning outcomes?

BACKGROUND

Multimodal data collection

Many nomadic inquiry-type projects allow students to collect data in multimodal ways, and to engage with that data upon returning to the classroom. For example, the BioKIDS program uses handheld devices to enable students to collect numeric and classification data about organisms in their schoolyard, providing a streamlined way for students to collect and categorize their findings [20]. The MyArtSpace program (Vavoula et. al., 2009) allows students to collect multimodal information on topics defined by their teachers in pre-visit activities. Through the program, students can use a mobile phone to take pictures, record sounds, write comments, and "collect" objects in the museum by typing in the object's code number. Informal learning involves multisensory experiences; providing multiple ways through which to capture the experience may facilitate sensemaking. Collecting this multimodal data provides students with different opportunities to make sense of their experiences.

Using voice memos for reflection

Supporting reflection can help students mindfully collect and make sense of data and new information, and can improve learning outcomes [6, 7]. Reflecting on museum experiences by watching videos, looking at photos, and reviewing personal observations increases visitor learning and sense-making about the museum experience [2]. Prompting students to record audio memos immediately after collecting a piece of data in the museum may encourage careful annotation and boost conceptual understanding [19].

Using tags for efficient annotation

Several mobile programs allow students to annotate and make meaning of their data by tagging, appending notes to their primary data, or recording associated memos. Tagging, a process of selecting keywords to describe or label an information object, can enable visitors to collect and organize their data or experiences in museums for later investigation [13]. Further, the process of tagging can encourage visitors to engage in sensemaking dialogue (i.e. [5, 10, 22].

Tagging is a way to support students to efficiently make sense of and organize their data during a field. Supporting students to tag their data encourages them to focus on essential aspects of what they are observing. To better connect the informal and formal learning environments, tags can be created by students prior to the field trip. In this case, the tags can represent students prior knowledge and predictions about what they may encounter during their field trip. Using preset tags can reduce the cognitive load of sensemaking in a novel environment by restricting the evaluative scope of the experience [13].

Zydeco program design

Based on this prior research, we developed the Zydeco system, a set of tools to support nomadic project-based inquiry between the classroom and out-of-school settings such as museums, zoos, parks, and aquaria [4, 13]. The Zydeco system includes a website and handheld tools to help students and teachers plan an investigation; collect and annotate evidence, and sort and analyze the evidence in order to make scientific explanations to complete their investigations. In class, before going on a field trip, the students begin to investigate a driving question or challenge. This question or prompt is related to their science curriculum and is deep, interesting, open-ended, and feasible (i.e. it can be investigated through evidence collected during the field trip) to allow for sustained inquiry [11].

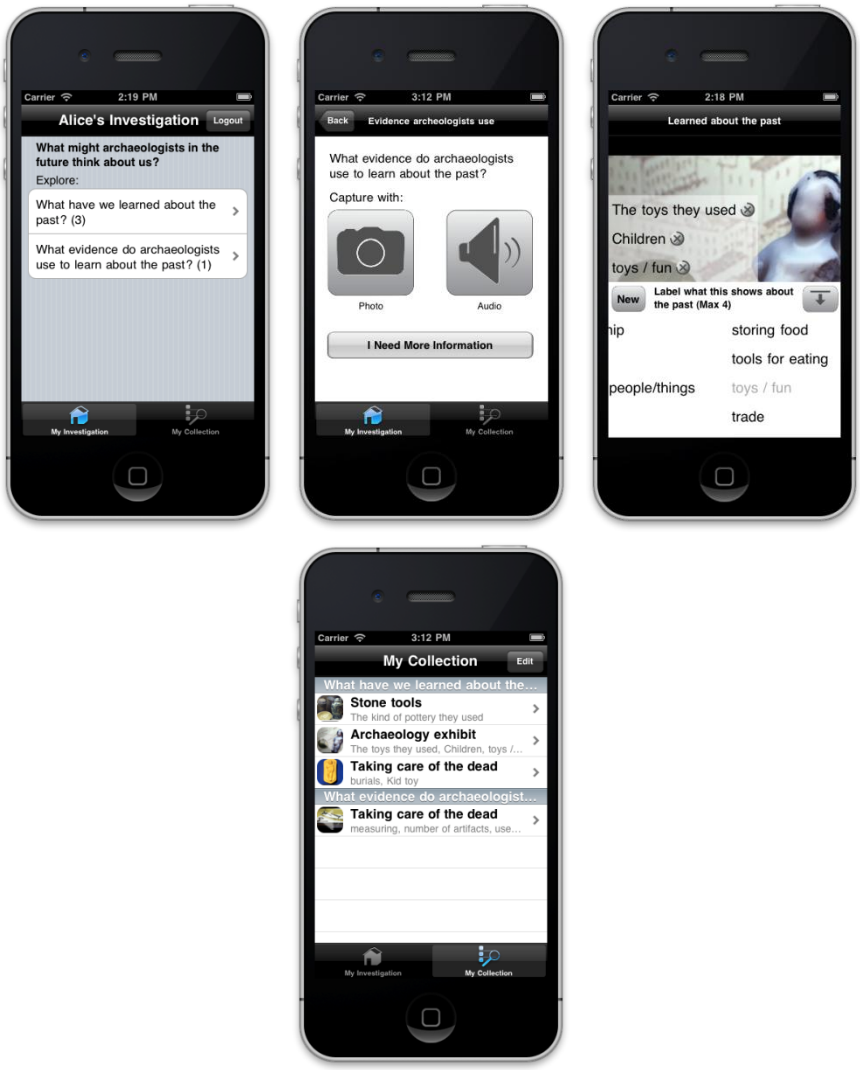

Figure 1: Parts of the Zydeco inquiry application. (top left) Driving question and sub-questions. (top right) Choosing how to collect data. (bottom left) Tagging data. (bottom right) Reviewing collected data.

The class defines sub-questions that will help them address the driving question or prompt, and predicts what evidence they might find to answer the question. These predictions will be the preset tags that students use during their field trip. The subquestions and the potential annotations are entered into the website. When students log in to the iPod Touch-based Zydeco application in the museum, their investigation - including the driving question, subquestions, and tags – is downloaded automatically to the device. Students then use the Zydeco app to capture evidence in the form of photos and audio memos to address the subquestions. Once students collect a piece of evidence, they are prompted to record a voice memo to explain why that evidence helps them answer the subquestion. Afterward, students are prompted to tag the photo using either the preset tags they defined in the classroom, or by adding a new tag or voice memo. Upon returning to the classroom, students can use the website to access, organize, analyze, and construct explanations using the data they collected.

METHODOLOGY

This study focuses on 85 seventh-graders from a diverse school district in which 56% of the students qualify for free- or reduced-price lunch. The students studied pre-historical communities and archaeology in their science and social studies classes, and attended an Archaeology Day program at a Natural History Museum. In science class, the particular focus was on how archeologists and paleontologists find and evaluate evidence to learn about the past. The Archaeology Day field trip involved ten areas where students could interact with docents and objects and view exhibits. The ten stations were grouped three different floors, and student groups spent 35 minutes on each floor. Students collected data using the Zydeco program on one of the three floors, and used worksheets to guide their learning on the other two floors, such that one third of the students on each floor used the Zydeco program to collect data. In this study, only data from students using the Zydeco program was evaluated.

Students prepared for the field trip by using the Zydeco handheld program to completing a mini-investigation about evaluating evidence. They also were introduced to two questions: "What have we learned about the past?" and "What evidence do archaeologists use to learn about the past?" The two questions were designed to encourage students to consider how archaeologists develop theories about the past by finding and interpreting a wide range of evidence. Through a class discussion, the students identified what they knew and wanted to learn relative to these two questions in the museum. Tags were extracted from these questions and comments. For example, a student asked the question "What kinds of jobs did people have?" when considering what she wanted to know about what archaeologists have learned about the past. From this student's question, the tag "jobs" was extracted.

The two questions and these "preset" tags were uploaded to the handheld devices prior to the students' visit to the museum. Students collected primary data in the form of photos and voice memos in the museum to answer the two questions. Next, they were prompted to record an additional voice memo explaining how the photo or voice memo helped them answer the selected question. Forty-six of the students were randomly assigned one of two different types of prompts to encourage reflection. The first type of prompt was a general prompt asking "What does this evidence tell you?" The second type of prompt was specific to the sub-question, asking "How does this show how archaeologists analyze evidence?" or "How does this show you what archaeologists have learned about the past?" Finally, they were prompted on the device to label the data, either using the preset tags or creating their own, new tags.

After the experience and one day of post-visit activities, students took a post-test designed to assess their understanding of focal archaeological concepts. Student ability levels and prior knowledge was assessed through a unit test on archaeology that students had taken one week prior to the field trip. Student scores on the unit test were z-scored. Students were grouped into three "ability levels" based on this z-scored assessment: below average (.5 standard deviations below the mean or lower), average (between .49 standard deviations below and above the mean), and above average (.5 standard deviations above the mean and higher).

Students' voice memos were transcribed from each mobile device. Two researchers independently coded 10% of the overall data to establish inter rater reliability. Tags were coded based on the accuracy relative to the primary data they described (Cohen's kappa = .755; 100% agreement after discussion), the subject of the photo (Cohen's kappa = .915; 100% agreement), and whether they corresponded with voice memo explanations (Cohen's kappa =.900; 97% agreement). Voice memo explanations annotating photos were coded for relevance to the photo, accuracy, who was speaking on the voice memo, and content (94% agreement).

ANALYSIS

Each student collected an average of 5 pieces of primary data. Most of this primary data was in the form of photos (98%); only 10 voice memos were recorded as primary data. Of the photos that were recorded, 87.2% had archaeological subjects. The remaining photos were of other objects in the museum, such as geological samples, fossils, and taxidermied animals. This analysis focuses on the archaeological photos and associated metadata (tags and voice memos). See table 1for a summary of the data that was collected by students during the field trial.

		Number *(percent)*	**Average per student *(SD)***
Primary data overall	**Photos**	460	5 *(3.1)*
	Voice memos	10	0 *(0.4)*
	Photos with archaeological subjects	401 *(87.2%)*	5 *(3.1)*
Metadata: archaeological photos only	**Total voice memos**	258	3 *(3.0)*
	Accurate voice memos	238 *(92.2%)*	3 (3.0)
	Total tags	749	9 *(7.0)*
	Accurate tags	597 *(79.7%)*	7 *(5.3)*
	Preset tags	559 *(74.6%)*	7 *(6.6)*

Table 1: Summary of primary data and associated metadata collected in field trial.

Students' use of tags

Use of tags varied significantly among the students. Students could apply up to four tags per photo. Forty percent of students applied an average of only one tag to each photo, and 35% applied an average of two tags per photo. Of the 749 total tags that were used to label archaeological photos, 79.7% were accurate, suggesting that students were usually mindful when labeling their photos with tags. Nearly three-quarters of the tags that students used to annotate archaeological data were selected from the preset tags the classes created prior to their field trip in the classroom.

Tags generally fell into one of four categories: naming the object (i.e. "canoe" or "pottery"), categorizing the object in terms of what types of evidence it provided for archaeologists (i.e. "jobs" as a tag for a birchbark basket, "how tools change" as a tag for a series of stone tools organized by age, or "where people lived" for a set of artifacts found locally), describing how the object might have been used by ancient societies ("transportation" as a tag for a canoe, or "writing" as a tag for an inkwell). Occasionally, students also used tags to describe the time period or locale where an object was found (i.e. "ice-age" for a mastodon skeleton, or "underwater" for a set of artifacts recovered from a shipwreck).

Students used the preset tags that they created in the classroom more frequently than they created their own tags during the museum visit. There may be explained in several ways. First, the preset tags were created by the students, and used language and concepts related to students' prior knowledge about archaeology. Thus, using these tags to annotate data allowed students to make sense and classify the data they were collecting in familiar terms. Further, preset tags were also easier for students to use than making a new tag, as they were pre-entered, and required no additional typing. However, since the preset tags could be applied to data by just tapping on them, students may have inadvertently selected some of the preset tags. Creating a new tag is more difficult, and requires more keystrokes and thoughtful analysis as students to actively type in new information. Further evidence to support this idea is that preset tags (74.8%) were less likely to be accurate than non-preset tags (94.2%) (Chi square, $p<0.001$).

Student ability level predicted 8% of between-student differences in the percentage of tags that were accurate ($p<0.012$). This suggests that students with higher ability levels were slightly more successful at tagging their photos accurately than students with lower ability levels. However, percentage and number of total tags a student used that were preset were not significantly related to student ability.

Voice memos

The audio prompts were designed to help students of all ability levels reflect on the data they had collected before writing tags. We hoped that, by encouraging students to reflect about the significance or meaning of their photos, they would annotate their photos more thoughtfully and develop a better understanding of the concepts represented by the objects in the museum. Students were not required to record an audio memo for each photo they took, and nearly a quarter of students did not record any voice memos.

Students recorded their own thoughts on the voice memos more frequently than they recorded other students or educators on the voice memos: 17.4% of voice memos included others' voices, and 96.1% of voice memos included students' thoughts. Students recorded a variety of ideas in their voice memos. Students most frequently explained the use of the objects depicted in their data (76.0%). For example, one student recorded the following voice memo about a spearpoint: "I think it could have been used for hunting and killing and shedding animals' skin." In addition, 67.8% of the accurate voice memos included students naming their data. For example, a student recorded the memo "It's a mummy" to annotate a photo of a model of a mummy. Students occasionally described what or how a scientist would learn from the depicted object. For example, one student recorded a memo about a photo of a series of primate and human skulls, stating, "These are the skeletons of primates to see how similar human are to primates, and so we could have evolved from them." This type of idea was included in only 5.2% of the voice memos recorded. In 11.2% of voice memos, students recorded affective reactions, such as: "These are the diagrams of their houses and how big it was and how it was like, and its really cool!" For 6.3% of voice memos, students made connections between the data and everyday life. For example, one student recorded the following memo about a gorilla skull: "I think this is a gorilla with crooked teeth, because they didn't have braces back then, and I think this is a gorilla." Only one student read the label of an object as a voice memo. See table 2 for a summary of how students used the voice memos.

Students with higher ability levels included more information in the comments they recorded on their voice memos ($p<0.001$). For example, one student said "I believe this here is a toy of a spinning top, and I also believe that this is a toy because of the fact that I can't find …I don't believe I can find any other use for a top that spins around at such small size with a whip that contains how it can spin around. I think it was used for child entertainment. And that's my hypothesis." This student named the object, explained its use, and then made connections to his understanding of how such objects are typically used today. In contrast, a typical comment by a lower-ability student included limited information. For example, when describing a similar display, a lower-ability student stated: “These are bones.” Higher ability-level students were also more likely to express affective reactions in their voice memos than average ability and low ability students ($p<0.05$).

				Ability level		
			Total	**Above average**	**Average**	**Below average**
Number of students using voice memos			58 (77.3%)	18 (66.7%)	18 (81.9%)	22 (84.6%)
Number of inaccurate / incomplete voice memos			20 (8.8%)	14**	3**	3**
Number of accurate voice memos			208 (91.2%)	70	62	76
Frequency category of infomation recorded in accurate memos (percent within accurate memos for each ability level)	**Recorded others**	Docent talking	32 (15.4%)	10 (14.2%)	10 (16.1%)	12 (15.8%)
		Other student	6 (2.9%)	4 (5.7%)	3 (4.8%)	4 (5.2%)
		Total	49	17	14	18
	Recorded self	reading a label	1 (0.5%)	0	0	1 (1.0%)
		naming an object	141 (67.8%)	53 (75.7%)	35 (56.5%)	53 (69.7%)
		explanation of use or meaning of objects	158 (76.0%)	51 (73.0%)	47 (75.8%)	60 (78.9%)
		Explanation of what or how scientists learn from objects	11 (5.2%)	1 (1.4%)	5 (8.1%)	5 (6.6%)
		affective reactions	23 (11.1%)	3* (4.3%)	5* (8.1%)	15* (19.7%)
		making connections	13 (6.3%)	3 (4.3%)	3 (4.8%)	7 (9.2%)
		Total	347	111***	95***	141***

**=p<0.05, **=p<0.01, ***=p<0.001*

Table 2: Characteristics of voice memos recorded by students of different ability levels.

The total number of voice memos, and the likelihood of a student recording a voice memo was not related to students’ ability level. In addition, there was no significant relationship between thenumber of accurate voice memos recorded and student ability. However, the number of incorrect or inaccurate voice memos a student generated was related to the ability level of the student ($p<0.01$). Lower-ability students were more likely to record inaccurate voice memos.

Finally, in this study, forty-six of the students were randomly assigned mobile device with either general or specific prompt. We analyzed how these different types of prompts impacted student data collection strategies. Chi-Square tests showed that the number of voice memos recorded by students and the accuracy of voice memo recorded were not significantly related to the type of the prompt students received.

Relationship between tags and voice memos

Overall, 76.5% of students used voice memos, and 68.5% of tags were accompanied by voice memo metadata. The number of voice memos used per photo had a small but significant correlation with the number of tags used per photo, indicating that students who used voice memos more frequently were likely to use more tags than students who used fewer or no voice memos ($r=.268$, $p<0.014$).

Each tag was coded by how closely it corresponded to its associated voice memo (See table 3 for a summary of the relationship between the tags and the voice memos). Tags were coded as directly related if they repeated language used in the voice memo, or if the tag and the voice memo could be directly categorized together. If the tag and the voice memo were related but could not be categorized together, they were classified as indirectly related. For example, one student recorded a voice memo about a photo of a flour grinding stone: "It was used to grind food into flour." She tagged the photo "getting food" and "cooking". These tags were classified as directly related to the voice memo. She also tagged the photo "farming," which was classified as indirectly related because grinding flour was associated with farming societies, but grinding flour is not a part of farming. If the tag and voice memo could not be associated together, the tag was classified as not related to the voice memo. For example, one student annotated a birchbark basket with the memo: "I think they would have to weave something make baskets." She tagged the same basket "ideas of beauty." This tag was classified as not related.

	number of tags (percent)	**number of accurate tags (% of tags in category)**	**number of preset tags**
Tags not accompanied by a voice memo	236 (31.5%)	208 (88.1%)	136 (57.6%)
Tag not related at all to the voice memo	196 *** (26.2%)	92 (46.9%***)	185 (94.4%*)
Tag indirectly related to voice memo	67 ***(8.9%)	59 (88.1%***)	62 (92.5%*)
Tag directly related to the voice memo	250 ***(33.4%)	238 (95.7%***)	176 (70.4%*)
Total	749 (100%)	597 (79.7%)	559 (74.6%)

(=p<0.05, ***=p<0.001)*

Table 3: Summary of relationship between tags and voice memos

Among the tags that were associated with voice memo metadata, one-third of the tags students chose were directly related to the audio memos that they recorded. Tags that were directly or indirectly related to the audio memos were significantly more likely to be accurate than tags that were not directly related to the audio memos (See table 3; Chi square; $p<0.001$). Further, tags that were directly related to the voice memo were less likely to be preset than tags that were not related or indirectly related to the voice memo (Chi square; $p<0.03$). There may be two explanations for this. First, students who used tags to summarize their voice memos may have created tags in order to more directly represent the content of the voice memo. Tags that were categorized as directly related to the voice memo are also less likely to have been inadvertently selected by students, and, as mentioned previously, preset tags were easy to accidentally append to photos. Indeed, preset tags were significantly less likely to be accurate when they were not related to the voice memo (45%) than they were if they were indirectly (89%) or directly (95%) related to the voice memo ($p<0.001$). There was no significant relationship between student ability level and how or whether their tags corresponded with voice memo.

Sensemaking supports and learning outcomes

Our last set of analyses addresses the question of how different sensemaking supports – voice memos, tags, and archaeological photos – relate to student learning outcomes when controlling for prior knowledge and ability. In each analysis, we controlled for prior knowledge and ability using the z-scored grade on their pre-program unit test on archaeology.

Our analysis showed no association between the number of accurate voice memos, photos, or tags used and learning outcomes when controlling for ability. This may be explained because the amount of data collected by each student varied dramatically (See table 1). However, the percent of tags a student used that were accurate was associated with higher learning outcomes, when controlling for prior knowledge and ability ($B=5.124$, $p<0.041$). In other words, a 10% increase in tag accuracy was associated with a 0.1 standard deviation increase on the post-test score. This suggests that, mindfulness during the process of tagging – analyzing and annotating what they saw in the museum in terms of their prior knowledge and new understandings - was associated with higher learning outcomes. Thus, tagging may encourage some students to be more mindful about their experience in the museum.

DISCUSSION

This research supports three main findings:

- Both reflective voice memos and tags can support student sensemaking during nomadic inquiry, in complementary but different ways.
- The use of voice memos and tags varied greatly among students regardless of levels of prior knowledge and ability, although higher-ability students recorded a higher density of information when they recorded their own thoughts in voice memos.
- Reflective voice memos has the potential to support mindful tagging for some students, but may encourage careless tagging among other students.

Student use of the Zydeco tool varied dramatically within and between students of different levels of prior knowledge and ability. The number of photos collected by a student varied from 1 to 16, and student use of tags and voice memo metadata varied greatly. Zydeco allows students flexibility and choice in the amount and type of data they collect. However, the small amount of data collected by some students suggests that some students may not have understood the purpose of data collection, or may not have felt comfortable with using the program [4].

Students used voice memos for different purposes. Some voice memos recorded docents' or peers' conversation, while others involved student's comments with different degrees and types of sense-making. The usage of voice memo and the accuracy of voice memosare not significantly dependent on students' ability level, which indicates that the Zydeco system accommodates differences in learning styles across ability levels. On average, students primarily used voice memos to name the objects, or explain the usage of the objects, regardless of students'ability level and prior knowledge. Surprisingly, students with the highest level of prior knowledgeand ability made more affective comments on voice memos compared with other two lower levels of students. This suggests that students with higher ability and prior knowledge were personally engaged with the exhibits, while students with lower ability levels and prior knowledge levels were less likely to engage in this way with exhibits through data collection.

Nearly all students used both preset tags and created their own tags for photos, regardless of prior ability level. Preset tags were less likely to be accurate than the non-preset tags. The most likely explanation for this is that selecting preset tags could be done easily and did not require the mindfulness required to type in a new tag. Supporting this idea, among preset tags that were associated with voice memos, those that corresponded either directly or indirectly with voice memos were more likely to be accurate than preset tags that were not related at al to the voice memo.

The percentage of tags used that were accurate was positively related to learning outcomes when controlling for student ability levels. This suggests that mindful data annotation in the museum can support learning across settings. Tags that were directly or indirectly related to voice memos were more likely to be accurate than tags that were not related to voice memos or tags that were not associated with a voice memo. This suggests that, for some students, prompting voice memos to reflect on data collected prior to tagging has the potential to encourage mindful tagging. However, for other students, a high percentage of tags were unrelated to the voice memos and inaccurate. For these students, recording voice memos seems to be related to carelessness in tagging, perhaps, due to the redundancy perceived in recording both voice memo and tag metadata.

CONCLUSIONS

By prompting students to annotate their primary data with voice memos and tags, the Zydeco system may encourage students to be more engaged during their investigation, and helps them to collect hands-on and minds-on data.Although preset tags provide students access to prior knowledge and can help students connect the museum experience to their formal experience and learning, some students seem to apply these preset tags carelessly. Since the percentage of tags used that are accurate is related to learning outcomes, more research is needed to support students to use these tags mindfully.

In conclusion, most students used photos, tags, and voice memos in a variety of different, yet complementary, ways to support sensemaking. Affording this variety of data collection can help student with different learning styles engage in data collection, and permits students to personalize their own record of their nomadic inquiry.

ACKNOWLEDGMENTS

We are grateful for the support and guidance of Ray Silverman and Bradley Taylor of the University of Michigan Museum Studies Program, Kira Berman, Amy Harris, Lisa Young, and the Exhibit Museum of Natural History at the University of Michigan, and Tonia Porterfield and Barbara Karalash. This work was supported by a Fellowship for Dissertation Research in Museum Studies, and NSF Grant DRL 1020027. Any opinions and findings expressed in this material are those of the authors and do not necessarily reflect those of the National Science Foundation.

REFERENCES

[1] Bamberger, Y. and Tal, T. Learning in a Personal Context: Levels of Choice in a Free Choice Learning Environment in Science and Natural History Museums. Science Education, 91, 1 (January 2007), 75-95.

[2] Barry, A. Creating A Virtuous Circle Between A Museum's On-line And Physical Spaces. In Proceedings of the Museums and the Web 2006 Conference (Toronto, March 1, 2006, 2006),

[3] Brown, Collins, & Duguid, Situated cognition and the culture of learning. Educational Researcher, 1989, 18, 1, 32-42.

[4] Cahill, C., Kuhn, A., Schmoll, S., Lo, W.-T., McNally, B. and Quintana, C. Mobile Learning in Museums: How Mobile Supports for Learning Influence Student Behavior. In Proceedings of the Interaction Design and Children Conference (Ann Arbor, MI, June 20-23, 2011)

[5] Cheverst, K., Davies, N., Mitchell, K. and Friday, A. Experiences of Developing and Deploying a Context- Aware Tourist Guide: The GUIDE Project. In Proceedings of the 6th Annual International Conference on Mobile Computing and Networking Conference (Boston, MA, 2000), 20-31.

[6] Chi, M. T. H., De Leeuw, N., Chiu, M.-H. and Lavancher, C. Eliciting self-explanations improves understanding. Cognitive Science, 1994, 18, 3, 439-477.

[7] Davis, E. A. Prompting middle school science students for productive reflection: Generic and directed prompts. Journal of the Learning Sciences, 2003, 12, 1, 91-142.

[8] Falk, & Dierking. Learning from Museums: Visitor Experience and the Making of Meaning. Altamira, Walnut Creek, CA, 2000.

[9] Hsi, S. A study of user experiences mediated by nomadic web content in a museum. Journal of Computer Assisted Learning, 19, 3 (September 2003), 308-319.

[10] Hsi & Fait. RFID enhances visitors' museum experience at the Exploratorium. Communications of the ACM 2005, 48, 9, 60-65.

[11] Krajcik, J. S. and Blumenfeld, P. C. Project-based learning. Cambridge, MA, 2006.

[12] Krajcik, J. S. and Hunter, H. E. Artemis Astronomy Research Investigation Teacher Guide. Kendall/Hunt Publishing Company, Dubuque, Iowa, 2004.

[13] Kuhn, A., Cahill, C., Quintana, C. and Schmoll, S. Using Tags to Encourage Reflection and Annotation on Data During Nomadic Inquiry. In Proceedings of the CHI 2011 Conference (Vancouver, BC, Canada, May 7-12, 2011)

[14] Lave, J. and Wenger, E. Situated learning: Legitimate peripheral participation. Cambridge University Press, New York, 1991.

[15] Luchini, K., Quintana, C. and Soloway, E. Design guidelines for learner-centered handheld tools. In Proceedings of the SIGCHI Conference on Human Factors in Comp. Systems (Vienna, Austria, April 24-29, 2004)135-142.

[16] National Research Council. National Science Education Standards. Nat. Academy Press, Washington, DC, 1996.

[17] Piaget, J. Piaget's theory. John Wiley and Sons, New York, 1970.

[18] Quintana, C., Eng, J., Carra, A., Wu, H.-K. and Soloway, E. Symphony: A case study in extending learner-centered design through process space analysis. In Proceedings of the CHI '99 Conference (Pittsburgh, PA, 1999),

[19] Quintana, Reiser, Davis, Krajcik, Fretz, Duncan, Kyza, Edelson, and Soloway. A scaffolding design framework for software to support science inquiry. Journal of the Learning Sciences, 13, 3 (July 2004), 337-386.

[20] Songer, N. B. BioKIDS: An animated conversation on the development of complex reasoning in science. Cambridge University Press, Cambridge MA, 2006.

[21] Squire, K. D. and Jan, M. Mad City Mystery: Developing Scientific Argumentation Skills with a Place-based Augmented Reality Game on Handheld Computers. Journal of Science Education and Technology, 16, 1, 5-29. 2007.

[22] Vavoula, G., Sharples, M., Rudman, P., Meek, J. and Lonsdale, P. MyArtSpace: Design and evaluation of support for learning with multimedia phones between classrooms and museums. Computers & Education, 53, 2 (September 2009), 286-299.