Becoming Makers: Examining ‘Making’ Literacy in the Elementary School Science Classroom

Sharon Lynn Chu¹, Elizabeth Deuermeier², Rachel Martin², Francis Quek³, Alexander Berman³,
Mario Suarez², Niloofar Zarei³, Beth Nam¹ and Colin Banigan¹

¹The StoryLab@Texas A&M, ²Department of Teaching, Learning & Culture,

³TAMU Embodied Interaction Lab. Texas A&M University.

[sharilyn, e.deuermeier, rkt002, quek, anberman, suarezi, n.zarei.3001, namieu, cbanigan]@tamu.edu

ABSTRACT

This paper extends the concept of digital literacy and applies it to Making. Through case descriptions, we contribute an understanding of how children can become or fail to become individuals literate in Making within a formal learning context. Our analysis draws from video recordings and other data sources of two 4th grade classrooms in which the students, who had already participated in 1.5 years of more structured ‘makified activities’, engaged in an open-ended, exploration-based, and playful task that was more in line with the spirit of Making. Student teams were classified as ‘high in Making literacy’ and ‘low in Making literacy’, revealing how Making literacy was expressed at the level of skills, mental models, and practices in various ways for different students. Our qualitative analysis demonstrates what burgeoning Making literacy may mean in a public elementary school classroom, paving the way for a vision of a time when Making becomes generalized practice.

Author Keywords

Maker; Making; Children; Literacy; Science; Elementary school; Electronics.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

The Maker movement has tremendous promise to enable children to participate in empowering learning experiences through technology use. Studies of children’s Making – “an active process of building, designing, and innovating with tools and materials to produce shareable artifacts” [1] – has gained much traction in the IDC community (e.g., [2, 3]). Yet, we still have insufficient understanding of how learning interrelates with Making. In this paper, our focus is the

public school classroom as a site for the development of ‘Making’ literacy and learning. Our research goal is to contribute to the understanding of how children become or fail to become Makers within formal learning contexts. Understanding how students may learn Making and become Makers in formal settings may inform us on how the classroom may be a site where children from a diversity of backgrounds are inducted into the Maker movement. Making gains additional significance when it is used in an educational environment where it is a medium for learning. Reading, writing and speaking have traditionally been the main ways by which learning takes place. As new platforms and screen-based media emerged, it was quickly recognized that this literacy needed to evolve to include multimedia and digital technologies, such as Internet search skills. With the deep interest to bring the Maker movement into education, it is imperative that we now begin to understand literacy in the context of Making. Key questions to be asked include not only ‘how does a student become literate in Making?’, but first of all, the question ‘what does it mean for a student to be literate in Making?’ begs consideration.

BACKGROUND: LITERACY

Literacy is defined by Vee [4] as “a human facility with a symbolic and infrastructural technology that can be used for creative, communicative and rhetorical purposes”. Literacy has traditionally been associated with skills in reading and writing that enable an individual to participate adequately and effectively in society, but many other concepts of literacy have been put forth. ‘Media literacy’ is “the ability to access...media, to understand and to critically evaluate different aspects of the media and media content and to create communications in a variety of contexts” [5]. ‘Digital literacy’ includes skills like searching, organizing and presenting digital information online [6].

Literacy has at its core processes of meaning-making through forms of representation [7]. A literate individual is able and willing to engage with the medium to create new meaning. A useful framework proposed by Meyers et al. [8] describes three aspects of digital literacy: i) *Skills* – “a set of discrete abilities or behaviors”, often equated with competencies such as knowing the Boolean operators to create effective search strings in a search engine; ii) *Mental models* – “the application of abstract mental models to activities involving digital content”, essentially ‘habits of mind’ that

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from Permissions@acm.org.

IDC '17, June 27–30, 2017, Stanford, CA, USA

© 2017 Association for Computing Machinery.

ACM ISBN 978-1-4503-4921-5/17/06...\$15.00

DOI: <http://dx.doi.org/10.1145/3078072.3079745>

one may apply to generalized contexts and problems (e.g., being able to evaluate the authority of internet sources); and iii) *Practices* – “engagement in a set of practices involving digital tools and media that are deeply embedded in a particular context or activity”, i.e., the general capability of an individual to function within a physical and social environment characterized by digitality, which typically is accompanied with a sense of identity.

TOWARD ‘MAKING’ LITERACY

To our knowledge, there has been little examination of the concept of literacy in terms of Making. DiSessa [9] argues that for a literacy to arise, the associated technology must first become central or infrastructural to the society’s communication practices. For instance, although writings were available very early on, the importance of reading and writing literacy came into play much later [4]. As Making technologies become diversified in their uses and more pervasive in everyday settings, there is increasing pressure to understand the form that Making literacy will take and what it will entail. Some prior work pave the way for us to think about the issue. Meyers et al. [8] move literacy within the scope of the Maker through another perspective on digital literacy: rather than seeing the literate individual as a consumer who is able and willing to engage in interpretive processes to (re)produce meaning, they advance the notion of *the participatory creator* – “a digitally literate person who is able to and see themselves as someone who engages in the activity of digital information creation”.

In her dissertation, Litts [1] uses the lens of ‘multiliteracies’ to analyze learning in three types of informal makerspaces (libraries, after school programs, and museums). Multiliteracies recognizes that learning is situated and embedded in material and socio-cultural contexts, and that there are many ways for people to learn [10]. Litts proposes three design threads emerging from her analysis: activity (making trajectory and artifact), identity (maker), and community (makerspace). Using this framework, Litts asserts for instance that “not every classroom can become a makerspace, since makerspaces require a community element that transcends the systemic limitations of a traditional classroom”.

The area of ‘computational thinking’ expanded to ‘computational literacy’ that recognizes “the computer as the material basis of the literacy” [4] may also be relevant to Making literacy. Steinkuehler and Johnson [11] report on two case studies of groups engaging in ‘modding’ (modifications) of the well-known game *World of Warcraft*. Mods can be seen as computational artifacts, the products of a specific kind of computational literacy. Integrating data from online forums, design documents and interviews, they propose that a potential learning trajectory for computational literacy moves first from consumption (being mod users) to production (becoming mod critics and then mod adapters) to more complex or professional forms (full-fledged mod producers). The question that Steinkuehler and Johnson do not answer is under what conditions does participa-

tion evolve into production.

The Making literature has addressed to various degrees the three aspects of literacy from Meyers et al.’s [8] framework. At the level of ‘skills’, research that evaluate particular Making technology implementations and approaches, such as TouchWire [12] and I/O Stickers [13], tend to focus on specific abilities, e.g., wiring circuits, manipulating stickers, or the acquisition of knowledge sets, e.g., circuitry.

At the level of ‘mental models’, work that address the Maker mindset is relevant. Dougherty [14] introduced the idea of the ‘growth mindset’, the belief that one’s capabilities can continuously be improved, as being central to a Maker mindset. Regalla [15] offers reflections on how this growth mindset can be fostered in practice by, for example, training facilitators to withhold offering direct help, helping the children to step back from their process, and nurturing resilience in the face of frustration and failure. Some literature has looked at Making at the level of ‘practices’ or identity. Halverson and Sheridan [16] define Makers as the “identities of participation that people take on within the Maker movement”. Some like Martin and Dixon [17] have delineated characteristics perceived to be associated with the Maker individual (e.g., playful, learning-oriented, accepting of technology, risk-taking, enjoys sharing, etc.).

RESEARCH QUESTION

Digital literacy has been addressed in both formal and informal learning contexts, but in formal institutions, the goal of literacy formation must also consider the “constraints, motivational challenges and rigid discourses” of such contexts [8]. Meyers et al. [8] argue that informal environments are the best suited to actualize this form of digital literacy since “agents can express themselves most fully outside the bounds and constraints of a curricular agenda and standards”. The questions of interest to us then are: *i) Can students acquire Making literacy in the elementary school classroom?*; and *ii) How do students express their Making literacy in a Making-based class assignment?*

Our investigation of these questions adopts the approach of studying how students, having acquired basic Making skills and being familiar with the concept of Making through close-ended Making activities, engage in Making at the level of mental models and practices through an open-ended Making activity for the first time.

STUDY CONTEXT

This study was part of a larger 3-year long research project that integrates Making into the science curriculum for 3rd, 4th, and 5th grade classes within a local public elementary school classroom. Each class engages for a week in a Making curriculum focused around a specific science topic every six weeks. This corresponds to one Making week for every science unit in the curriculum of that particular grade level. Activities during the Making weeks are designed by a team consisting of members with expertise in electrical engineering, computer science, child-computer interaction

and design, and education and classroom pedagogy, informed by feedback from the participating teachers. The allotted class length ranges from 45 minutes to 1.5 hours depending on the grade level. The number of students in each class ranges from 18 to 20.

We describe below an example of the activities that the students engaged in during the Making weeks for the first 1.5 years of the project in the science unit of ‘Matter and Energy: Mixtures and Solutions’. The students built an electronic mixer (see Figure 1) comprising of a basic electronic circuit with a geared rotating motor as the load and a switch made out of card stock and conductive copper tape. A 3D-printed mixer head was attached to the motor through a dowel rod so that the student can insert the head into a container and activate the motor. With their electronic mixer, students mixed glitter with water and made observations about the mixture. Other examples of Making activities in which the students engaged for other science units included building LED-embedded food chains, rotating solar system models, etc.

STUDY DESCRIPTION

The work reported in this paper specifically focused on two 4th grade Bilingual science classes, both taught by the same teacher. Class

Figure 2. Students working on their dioramas

1 had 19 participants and Class 2 had 18 participants, totaling to 37 participants (18 groups of two or three students). The study was conducted in the second semester of Year 2 of the research project, when the 37 participants had already participated in the first 1.5 years of Making curriculum as described above. In one of the Making weeks, the nature of the Making activity was changed. In contrast to the previous activities, the activity was made more open-ended, exploration-based, encompassing, and more playful.

The curriculum topic addressed during the focus Maker week was ‘Forms of Energy’. The learning goals for this unit were that students should be able to differentiate among the various forms of energy (including mechanical, sound, electrical, light, and heat or thermal energy. Minors’ assent was obtained from all the students prior to the study, and parents also provided written informed consent for their child to be observed and recorded during class. The focus Making week consisted of the following activities:

On Day 1, a review of the forms of energy was done by the teacher to ensure baseline science knowledge. On Day 2, students were put in groups of two or three. Each group was

assigned one form of energy, and the students were given a single instruction for the Maker activity: “Make a diorama that shows a model of your assigned form of energy using the materials available to you in any way that you want”.

The students were given a set of components (Figure 3), most of which they have encountered in previous Making weeks. From their engagement in the previous 1.5 years of Making weeks, the students had basic Making skills (building a basic electronic circuit to activate LEDs, and motors) and programming skills using the Arduino microcontroller board and the ArduBlockly interface (a block-based visual programming interface).

As in previous Making weeks, helpers were present in the classroom, but for this activity, students were let to work independently and without interruption from the adults, unless help was specifically requested by the children. The diorama-making activity was spread over Day 2 and Day 3. On Day 4, all student teams presented their final dioramas to the class, the teacher and the school principal. The students planned out a script and practiced at their tables before doing their presentations. Figure 2 shows the students working on their dioramas. On Day 5, the students filled in a questionnaire about their interest in Making and feedback about the Making week.

DATA ANALYSIS

Our research adopted a qualitative case study approach. Data sources included video recordings of each student team’s diorama presentation, the diorama drawings, pictures of the final diorama with electronics embedded, video recordings of the planning phase, planning sheets, and observation notes from helpers.

Two members of the research team watched the students’ presentations and together generated a summary of the concept of each diorama. Specifically, notes were taken on the components used, how the diorama modeled the type of energy assigned, and the role that Making broadly had in the diorama. Six student groups that had the most interesting presentations were selected for deeper analysis. Three pairs of coders were assigned two student groups each. All coders were familiar with the Maker movement. Each pair of coders consisted of one person from a technical background (computer science or engineering) and one person from a non-technical background (education or design). The data for each student group were collected from all the various sources identified earlier, and given to each coder pair. Each coder independently reviewed all the data, and then did a decomposition analysis of the dioramas: first, all the meaningful units of the diorama were identified (see Figure 5 for example of decomposition); each unit was then coded as being ‘technology-based’ or ‘non-technology’ (a technology-based unit could contain non-technology elements as well, as long as at least one technology component was integrated); and finally, the coders noted the function that

Figure 1. Mixer with motor

each unit served in the broader diorama with respect to the intended science concept. The coders from all pairs and the two members of the research team who did the initial group selection then met to compare and contrast the process and products of the student groups.

FINDINGS

RQ1: Can students acquire Making literacy in the elementary school classroom?

All the pairs managed to produce technology-based dioramas that were in line with the assignment instruction given. This suggests that at least at the level of skills, all the children knew how to Make. Figure 4 shows the 6 dioramas analyzed. We describe only two of them below because of space restrictions. Pairs 1 and 2 were assigned thermal energy to model. Pair 1 created a narrative around their form of energy of a camper who set up camp in the forest and lit up a fire to scare away a snake. Their presentation highlighted the camp fire as emanating heat. Out of the six components that made up their diorama, 3 had a technology component and 3 were simply arts-and-craft (see Figure 5). While other parts of their diorama related to science (“The sun makes the plants grow and the plants give us oxygen.”), the children made explicit links to thermal energy only for the camp fire. Thus, all of the other components, technology- or non-technology-based played a supporting role to provide context for the narrative. Pair 1 thus used Making both as the *illustrator* for the science concept, and to provide *context* to the concept.

Pair 2 created a literal representation of an LED circuit. Their concept was that “When we keep the light on all the day it gets hot. Today we’re going to show you how to turn on the light.” Their diorama had five meaningful units: an LED, a battery pack, the Arduino microcontroller, a resistor, and a laptop. Each element was drawn on the paper and the electronic component placed on top of the drawing except for the laptop drawing. While all their components were technology-based, not all had a functional role. The battery and the resistor, for example, were drawn in the diorama but were not used in the circuit. The children powered the LED from the Arduino running from the laptop, making the battery and resistor redundant. Pair 2 used Making to produce *exemplars* of science concepts themselves (LED for light, and the warm resistor for heat).

RQ2: How do students express their Making literacy in a Making-based class assignment?

We describe below how the students’ Making literacy was observed at the level of skills, mental models and practices.

Skills. Basic Making literacy skills that all the students were familiar with from the past 1.5 years of Making curriculum included connecting batteries and paper switches with loads, such as LEDs and motors, and programming how to switch on and off loads using the Arduino. In this first-time open-ended Maker activity, high literacy students were able to identify materials that they would need for the concept that they envisioned. For example, after deciding to use vibration

to generate sound for a mobile phone ringing, Diego and Daniella (Pair 5) identified the difference between the vibrating motor and the rotating motor, and quickly communicated to a helper that they needed to exchange their rotating motor for a vibrating one for their vibrating mobile phone concept. While even low literacy students could connect up circuits correctly once they were given the correct materials, they had

Figure 3. Components available to the students for Making

Figure 4. Dioramas analyzed (names have been changed to preserve anonymity)

Figure 5. Example of decomposition analysis (T: Technology-based; NT: Non-technology-based)

problems identifying the materials needed to operationalize their diorama concept. Annie and Christian in Pair 2, for example, included a resistor and a battery in their circuit when their LED was already being powered by an Arduino.

Mental models. Troubleshooting: In previous Making weeks, helpers had continuously reinforced troubleshooting as a key process in Making. Different troubleshooting strategies had been explained to the students, such as checking that wires were connected properly and that the battery packs were switched on. We observed that even lower literacy students could engage in such learnt troubleshooting during the open-ended activity. However, groups higher in Making literacy were able to *think of other ways to troubleshoot through exploration and experimentation*. For example, when Nicole and Vanessa (Pair 3) were stumped in how to reverse the motor on their push-pull machine, they tried two different methods: pulling the motor out and turning it over, and hand-cranking the machine using the wooden dowel until the machine was back to its starting position;

Ability to think about the science concept through the possibilities afforded by Making: Lower literacy students struggled in 3 ways: i) they could not think of a diorama concept that would use the available Making technologies to represent their form of energy; ii) when they came up with a concept, they could not see how to implement it using Making; or iii) there was a clear separation in their discussions of Making and science such that the two did not interrelate, and neither one was in service of the other.

For example, Ricardo and John (Pair 4) were assigned mechanical energy. They engaged in Making and were entirely proficient in building their LED circuits to represent the headlights in their diorama of a school bus, but their discussion of the bus door opening or the bus driver pressing the brake pedal as being instances of mechanical energy did not interrelate with their Making process. The two boys could correctly identify what was using mechanical energy in their diorama when asked, and they even brought a push-pull device with them during their presentation. However the device served no purpose in the diorama, and was not actually used during the presentation. This suggests that although Pair 4 understood the science concept and had adequate Making skills, they were poor in Making literacy. Conversely, students deemed higher in Making literacy went beyond simply connecting Making with the science concept, and grounded their dioramas in real-world scenarios. For instance, Diego and Daniella (Pair 5) made the connection between vibrating motors and the buzzing noise of their mobile phone on silent mode. Nicole and Vanessa (Pair 3) made connections between the concept of mechanical energy, rotating motors in a gear system, and the way one moves a toothbrush back and forward to brush teeth.

Ability to deconstruct the artifact to be made and figuring out how to realize each aspect through Making: In Pair 3's toothbrush diorama, for example, even though brushing one's teeth is typically viewed as a holistic activity rather than dis-

tinct pushing and pulling actions, Nicole and Vanessa deconstructed the concept in their discussions into separate movements. They were then able to reflect on how to actualize each movement using the rotating motor. Similarly, Jim and Adrianna (Pair 1) deconstructed their idea of heat energy scaring away animals into distinct units and they then operationalized each using Making through iterative problem-solving. E.g., the as a printed sun drawing in front of an LED in a 3D-printed cap (see B in Figure 5), a rotating motor to animate a tree drawing to simulate wind (see A in Figure 5). Groups that did not engage a deconstruction process tended to have a one-to-one mapping between a science concept and a technology artifact.

Practices. At the level of practices, some students were observed to be able to function better in a Making environment than others. Diego and Daniella (Pair 5) continuously *expressed their ideas* to each other throughout the design process and *shared all responsibilities* equally. Nicole and Vanessa (Pair 3) readily expressed their Making ideas to each other as well as to adult helpers, and reported that they actually enjoyed explaining themselves and how their artifacts worked. Students considered low in Making literacy had difficulty integrating Making as part of their typical collaboration practice. A case example is that of Ricardo and John (Pair 4) who were able to discuss with each other during the initial brainstorming phase when no Making was involved, but once they started the Making process, they worked completely independently of each other.

Another way by which students were deemed to be further away from the practice of Making was through the *delay of the Making process*. A case in point is Pair 6 who dedicated almost the whole two days to drawing their diorama, and spent only the last 20 minutes of the presentation day to engage in Making and had to rush to finish up their circuits. They did not necessarily dislike Making, but saw Making as an add-on to an art-and-craft-based diorama.

DISCUSSION

Our findings showed that after learning Making skills within classroom constraints (lockstepped instructions, fixed goals, minimal choices, etc.) for 1.5 years, the students could produce significant technology-based science dioramas in a Maker activity that was more in line with the spirit or essence of Making [16]. At a certain level then, the students would be considered as Makers. Indeed, questionnaires that we have collected throughout the prior Making weeks indicate that on self-report questions, a good proportion of the students are increasingly seeing themselves as Makers. They like Making, they are motivated to Make, and they feel that they can Make. However, their processes, behaviors and performance in the open-ended Maker activity showed a more nuanced picture. We extracted the themes of Making literacy from our analyses and present them in a framework shown in Table 1. A Making-literate student functions effectively at all three levels of skills, mental models and practices. Most Making skills can be taught and learnt. If the skills are correctly as-

simulated, students should be able to engage in Making, as many do by following tutorials and how-to guides on web-sites.

But Making-literate students also assimilate generalized ways of doing in their thinking and are able to apply them to various problems and scenarios. Literacy at the level of mental models can be basic in the sense that one simply applies learnt troubleshooting strategies to a particular problem. Greater literacy results in troubleshooting through the use of exploration and experimentation processes, or one being able to think about a concept or a problem through Making as grounded in real-life scenarios.

A Making-literate student further accepts Making as part of his/her ways of being and adopted it into his/her practices. Literacy at the level of practices is mostly emergent, and is challenging to inculcate through actual teaching. More literate children tend to have the drive and motivation to engage in Making. They enjoy the process and are not fearful of discussing or sharing what they did. Making takes on more of a normalized quality— they begin to perceive Making as something that you just do, and not as an add-on or something totally distinct from their typical activities.

CONCLUSION

Why is it important to begin thinking about Making literacy? We expect the Maker movement to evolve beyond being a ‘movement’ or a subculture. Making is poised to become a generalized rather than a specialized practice [4], essentially a literacy, just like textual and visual literacy today. Children learn to read till around third grade, after which they read to learn. The same may perhaps be expected for Making in the future: children may learn how to make and then use Making as a tool for learning. Our work provides a glimpse into how students who ‘know’ Making act and perform for a science

assignment.

ACKNOWLEDGMENTS

This work has been supported by NSF grant #DRL-1433770. We sincerely thank all the students and teachers.

REFERENCES

1. Litts, B.K., *Making learning: Makerspaces as learning environments*, in *Curriculum and Instruction*. 2015, The University of Wisconsin-Madison.
2. Holbert, N. *Bots for Tots: Building Inclusive Makerspaces by Leveraging Ways of Knowing*. in IDC 2016. ACM.
3. Wardrip, P.S. and L. Brahms. *Learning practices of making: developing a framework for design*. in IDC 2015. ACM.
4. Vee, A., *Understanding computer programming as a literacy*. *Literacy in Composition Studies*, 2013. 1(2): p. 42-64.
5. European, C., *A European approach to media literacy in the digital environment*. Official Journal of the European Union, 2007.
6. Gilster, P., *Digital literacy*. 1997: Wiley Computer Pub. New York.
7. Potter, J., *Digital media and learner identity: The new curatorship*. 2012: Springer.
8. Meyers, E.M., I. Erickson, and R.V. Small, *Digital literacy and informal learning environments: An introduction*. *Learning, media and technology*, 2013. 38(4): p. 355-367.
9. DiSessa, A.A., *Changing minds: Computers, learning, and literacy*. 2001: Mit Press.
10. Group, T.N.L., *A pedagogy of multiliteracies: Designing social futures*. *Harvard educational review*, 1996. 66(1): p. 60-93.
11. Steinkuehler, C. and B.Z. Johnson, *Computational Literacy in Online Games*. *International Journal of Gaming and Computer-Mediated Simulations*, 2009. 1(1): p. 53-65.
12. Saenz, M., et al. *Touch Wire: Interactive Tangible Electricity Game for Kids*. in TEI 2015. ACM.
13. Freed, N., et al. *Sticking together: handcrafting personalized communication interfaces*. in IDC 2011. ACM.
14. Dougherty, D., *The Maker Mindset*, in *Design, Make, Play: Growing the Next Generation of STEM Innovators*, M. Honey and D.E. Kanter, Editors. 2013, Routledge. p. 7-11.
15. Regalla, L., *Developing a maker mindset*. *Makeology: Makerspaces as Learning Environments*, 2016. 1: p. 257.
16. Halverson, E.R. and K. Sheridan, *The Maker Movement in Education*. *Harvard Educational Review*, 2014. 84(4): p. 495-504.
17. Martin, L. and C. Dixon. *Youth Conceptions of Making and the Maker Movement*. in IDC 2013. ACM.

Table 1. Aspects of Making Literacy

SKILLS	
Identifying parts and components	Learnt
Recognizing the functions of parts	Learnt
Connecting up circuits	Learnt
Basic programming using block-based interface	Learnt
MENTAL MODELS	
Troubleshooting	
Using troubleshooting strategies	Learnt
Troubleshooting through exploration and experimentation	Emergent
Thinking through Making possibilities	
Making for the sake of Making	Learnt
Grounding in real-world scenarios	Emergent
Deconstructing artifact	
One-to-one mapping of concept and Making component	Learnt
Problem-solving each aspect	Emergent
PRACTICES	
Self-identification as a Maker	Emergent
Integration of Making into collaboration practices	Emergent
Making as integral to one's activity	Emergent