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A Systemic Analysis of Making in Elementary Schools

Understanding Making for Children through Activity Theory

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***Abstract*—Based on an intensive semester-long study of designing and implementing curriculum-based Maker activities in 6 classes, this paper presents themes derived from a qualitative analysis of experience data using the framework of Activity Theory. Insights generated contribute to the understanding of the integration of Making into elementary schools at a systemic level.**

Keywords- making; maker; children; elementary school, activity theory

I. INTRODUCTION

Making has been defined broadly as the "hands-on production of artifacts that are technologically-enhanced" [1], and is typically associated with the 'Do-It-Yourself' construction of artifacts through 3D printing, electronics prototyping, and crafting. The widespread recognition that Making is beneficial for children's learning and self-development (e.g., [2]) has led to a growing number of studies investigating Making in learning environments. However, first, Making studies with children in formal contexts are limited, as compared to studies in summer camps, workshops, school clubs and afterschool programs, and second, the studies tend to focus on Making as insular and atomized experiences that children engage in. We seek to understand Making for children in formal contexts, particularly the school and classroom environment, at a broader, systemic level that takes into account factors beyond the individual child, and beyond the snapshot of a moment in the process of Making.

We first review prior work that have adopted larger-scale approaches to the study of Making for children in education. We then describe Engestrom's Activity theory [3] that we use as theoretical foundation. We present the Maker studies we conducted with children, and the dataset used in analysis for this paper logging the processes that we experienced during implementation of the studies. We then describe themes uncovered under the framework of Activity theory, and summarize implications of our findings in discussion.

II. MAKING IN EDUCATION

Few studies of Making with children in educational contexts address the issue at a systemic level. While still laudable, most focus on the evaluation of a specific technology, approach, program or curriculum design [4-7]. Prior literature and commentaries at a broader group or societal level can be found on the analysis of the Maker phenomenon in adult communities (e.g., [8-10]). We describe prior work in children's Making that are especially pertinent to our purpose below.

Drawing from their experiences organizing 40 programmable construction kits workshops with children, Katterfeldt, Dittert and Schelhowe [11] present 3 core ideas to guide the design of digital fabrication learning environments for children. Notably, they specify that: i) children need to be given the space and time to create with materials that are durable, but also with materials that support iteration; ii) a focus should be placed on personal ideas and concepts first, before the introduction of the technology; and iii) there is a need to blackbox certain parts of the technology to sustain self-efficacy in children. More interesting to us, they identify that their learning environment integrates 5 components: i) physical tools, materials and a programming environment; ii) a didactical workshop concept; iii) a context (a motivational topic, inviting parents for presentation); iv) a physical environment; and v) staff (with educational, technological and scientific background for planning, tutoring, evaluating).

Relevant work that are more tightly related to formal learning contexts, namely the school classroom include that of Berry et al. [12]. Based on observations and working notes gathered from discussions among high-level representatives at a series of technology education workshops and conferences, they provide broad recommendations as to the need to capitalize on teachers' abilities and for an appropriate infrastructure (hardware, software, library and collaborative space, and curriculum) to support the integration of digital fabrication in engineering education in elementary mathematics classrooms.

Flores and Springer [13] describe the assessment of self-directed learning that occurs in the Makerspace created at the Hillbrook Middle School to support science curriculum. They draw out several guidelines from their experiences, e.g., the need to allow for iteration in assessment, the need to allow for experimentation time as opposed to strictly structured classes, allowing students to set their own goals.

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Bekker et al. [14] describe the challenges of developing an integrated process for Making-related activities that is doable in primary/elementary and secondary/middle school. They synthesize insights that they gained from a stakeholders' (teachers, educational scientists, policy makers and publishers) meeting and three design explorations workshops with children. They present adaptations to an existing framework, renamed the Reflective Design-based Learning (RDBL) framework, which highlight 6 aspects: i) elements of a design process; ii) collaborative learning and reflection process; iii) learning goals and assessment; iv) design brief and project characteristics; v) properties of the learning environment; and vi) teacher's and children's role.

Last but not least, in a commentary on the Maker movement in education, Halverson and Sheridan [2] propose that Making can be studied at 3 levels: i) *Making* as a set of activities; ii) *Makerspaces* as communities of practice; and iii) *Makers* as identities of participation [emphasis theirs].

III. Theoretical Foundation

To realize the goal of understanding Making at a systemic level, we adopted the use of Activity Theory (AT) as theoretical foundation in our work. AT, initially proposed by Lev Vygotsky, the father of socio-cultural theory, and later extended by Engeström [3, 15] presents a system-level perspective of human activity as socially-situated and mediated by tools. More specifically, Engeström's reformulation of AT defined 6 key factors as influencing an activity: *1) Object:* An activity is necessarily directed to a certain goal motivated by one's needs or desires; *2) Subject:* The main actors in the activity are engaged in processes of internalization and externalization of thought; *3) Community:* Many other actors beside the subject contribute to the functioning of the activity system; *4) Tools:* Artifacts mediate the actors' thoughts and behaviors during engagement in the activity; *5) Division of labor:* Roles, responsibilities and tasks are distributed and divided throughout the activity system; and *6) Rules:* Explicit or implicit rules, conventions, and guidelines regulating action in the activity system. Engeström's AT is typically represented using the pyramid-shaped structure in Figure 1.

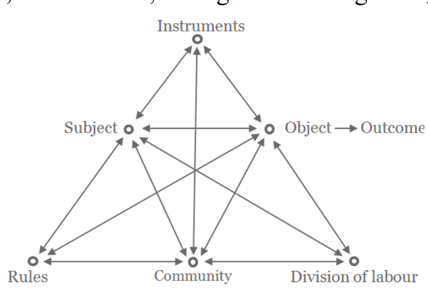

Figure 1. Engeström's Activity Theory

AT has been applied in many different contexts, including formal and informal educational contexts. For example, Jonassen and Rohrer-Murphy [16] proposed the use of AT as a framework for the analysis and design of constructivist learning environments. They provide a list of guiding questions for each component of the AT model to help in the analysis of an instructional activity situation. Mé ndez and Lacasa [17] studied the changes caused by the introduction of commercial video games in a group of 14 special needs students at a secondary/middle school using AT as foundation. They highlight interesting themes in their results, for instance, the existence of tensions in terms of the "political-administrative discourse" between the teacher who implemented the technology in her classroom, her collegues and government representatives, and the inversal of roles as students took on a more 'expert' role than the teacher in the use of the learning tool.

We are not aware of any prior work that has applied AT to the study of an activity system in terms of Making in learning. Thus, using AT as a conceptual tool, the specific objectives of our work is to analyze the design and implementation process of integrating Making into an elementary school curriculum, with an emphasis on the changes brought about, and the conflicts encountered.

IV. Study Description

We conducted a study that implemented Maker activities into the 3rd, 4th and 5th grade science and language arts classes at a local elementary school. Two classes for each grade were selected in collaboration with the school's administration for participation in this program. The class sizes ranged from 18 to 25 students, resulting in a total of 124 students participating in the program. We draw on our experiences of designing and implementing the program over a full school semester of 18 weeks for this paper. Eight different week-long Maker activities were implemented in each of the 6 classes. For each grade, this resulted in a Maker activity being organized in the classroom every 6 weeks. Our process was such that we had a team who designed the Maker activities through a curriculum-matching process and using the teacher of each class as informants. Two design pitches and critique sessions were organized with each teacher before the implementation week of the Maker activity in the classroom. We had another team present with the teacher in the classroom during the Maker activities. All students provided verbal assent to participate, and parents signed consent forms.

One example of a curriculum-integrated Maker activity that was designed and implemented is the 'vibrating earthquake model'. The activity related to the 3rd grade curriculum unit of 'rapid changes in earth and space' [18]. The learning goals for the unit were that earth consists of natural resources, that its surface is constantly changing, and that some changes occur rapidly. Examples of rapid changes to be studied include earthquakes. The Maker activity consisted of the students building a model of a village that sits on a pair of foam-core 'tectonic plates' with vibrating motors attached to its foundations (the plates are placed in a large plastic box on dowel rod 'pillars', attached with 3D-printed mountings). A layer of kitty litter is laid on top of the foam core plates, and the students created a village made of decorated origami houses on top of the kitty litter. When the vibrating motors taped to the 'foundation pillars' are activated,

Figure 2. Making the earthquake model

the foam core plates shake and separate, destroying the village and causing the kitty litter to fall into the crack of the separated plates, simulating an earthquake through Making. Figure 2 shows the students constructing the model.

V. DATASET AND ANALYSIS

We were interested in studying the integration of Making in the classroom as an activity system, and as such, we do not focus on the low-level operations and details of action during engagement in the Maker activity itself in this paper. The data used in our analysis of the curriculum-integrated Maker study through the lens of Activity Theory included observation and reflection notes after each cycle of design and implementation by several key members of the teams, notes of weekly meetings and discussions of our whole research group, and email logs of reports shared electronically among the team members. Our team members had a diversity of background and experiences, ranging from electrical engineering and art and design to psychology, education and teacher training. The dataset collected was used as material by 2 separate researchers to answer the AT list of guiding questions from Jonassen and Rohrer-Murphy [16]. Answers generated were then synthesized into one list of themes that were then classified under the 6 components of the AT framework. An axial coding process [19] of relating and grouping themes was done to finally generate high-level categories that we present as key findings.

VI. ANALYSIS FINDINGS

We present the high-level categories of themes under each of the 6 AT framework components:

A. Subject and Outcome:

The subjects in our activity system were elementary school children (7 to 12 years old), with a majority coming from underrepresented populations typically characterized by low school completion rate [20]. Some factors reported to distinguish these subpopulations include socioeconomic status, language, and cultural values [21]. The intended outcome of the overall system is student learning of concepts.

B. Community:

We found that the successful integration of Making into the school curriculum either required involvement from or implicitly involved a range of agents. We detail below the formal roles of stakeholders or contributors to the system in our study (Figure 3): *i) School district and board:* The school district determines the learning standards and curriculum to be used; *ii) Principal:* The school principal gives the most direct approval of the Maker program implementation, and handles the various requirement needs of the program and teachers' concerns; *iii) Curriculum coaches:* Sometimes also called 'subject coordinators', they define the 'mastery goals' of each subject based on the learning standards, oversee the quality of teaching of the teachers, and together with the principal, set the tone for the school environment and teaching style; *iv) Teachers:* Given their daily direct interaction with students, teachers carry the bulk of the responsibility of students' learning and define the lesson plan. As such, in a Making-integrated instructional system, they play a crucial albeit constantly evolving role; *v) 'Making' coordinator:* The coordinator liases with the teachers regularly, and functions as the link between the curriculum needs of the teachers and Making activities proposed by the design team; *vi) Technical designers:* Designers and engineers ideate and prototype Maker activities based on curriculum learning goals and teachers' input (e.g., students' problems in understanding a particular unit); and *vii) Helpers:* Manufacturing helpers help to produce enough Maker materials for the number of students in the classes, and classroom helpers assist in logistics during classroom implementation of the Maker activities.

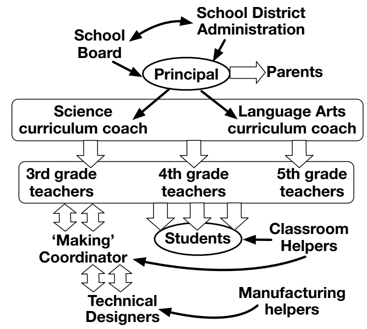

Figure 3. Community agents

C. Object:

1) Classroom goals:

Three of the teachers' classroom objectives were particularly conflicting with the successful integration of Making: 1) Teachers judged *children's engagement in the Making as inattention* to the regular flow of instruction where the children are expected to focus on the instruction constantly. Teachers' conceptualization of when children were 'on-task' versus 'off-task' required re-negotiation to include Making; 2) Exploratory behaviors that are typically inherent in Making activities often resulted in some degree of rowdiness among students, and conflicted with the teachers' goals of control and discipline. A new level of *balance between student-directed Making and exploration, and teacher-centered control* had to be reached; and 3) The sensitivity of the school to adhere to a strict set of 'mastery goals' are heightened in the 5th grade when students are tested in Science. This was expressed by *frequent classroom visits by the curriculum coaches* to ensure order and prescribed progress, which amplified further the two issues described before .

2) 'Making' goals:

Tensions became evident between the designers' point-of-view on the purpose of including Making into the classroom and the teachers' perspective. For the designers, Making served as a tool that enabled more effective learning and deeper understanding of concepts through tangibility, exploration and engagement. The teachers however, initially saw Making as a means to shore up students' interest, enthusiasm and excitement in the topic, with actual instruction being done traditionally. Over time however, teachers came to realize the value of Maker activities in being able to support their goal of student learning and improving test performance through changes in students' vocabulary use, increased engagement in troubleshooting, etc.

D. Tools:

1) Teaching materials:

Re-negotiation of teaching materials also reflected underlying tensions in the activity system. Teachers were used to the explicit step-by-step planning of lessons, and had difficulty teaching curriculum unit concepts using the Making materials and designed activity without *instruction guides, or 'Making-based' lesson plans*. Moreover, inconsistencies arose in whether teachers were able to bring in *references and other supporting materials* (e.g., accompanying videos, diagrams, etc.) that could couple with the Maker activity. While outside resources, such as mentors, online tools, or other professional development materials, are readily available for issues such as classroom management, the teachers were not consistently able to come up with supporting materials for the tailored Maker activities. Making in the classroom also highlighted the need for the advanced preparation of *'extension problems'*. Perhaps because of the hands-on nature of the activity, students completed tasks at widely different paces. While the need for the 'extension problems' to maintain alignment with the learning standards is clear, it was questionable whether the nature of the problems should be 'Making-based', which could be perceived as just creating more "busy" work for the student, or curriculum-based (e.g., writing reflections and observations in a diary, worksheets).

2) Making materials:

Perceptions of the Making materials were ambiguous: 1) The teacher initially saw the *Making materials as being something that the children need to assemble in an orderly manner* (the children were literally expected to not touch the material pending instruction of 'the next step' such as "Now connect the red wire to the battery –STOP and hands off when you are done." In one 4th grade session, the children had already experienced connecting up geared rotating motors and knew how to connect up vibrating motors in the next class. The children moved ahead of the teacher, causing the latter to see the 'disorder' as being disruptive; 2) The Making materials were viewed by the teachers as being 'foreign' to classroom environment. The discomfort created by the Making materials in the room was so evident that it caused some teachers to be unable to teach in their presence. For instance, some teachers wanted all Making material removed from the room before they continued instructing about the science that the Making was designed to support in the first place – the teachers saw a *barrier between the Making-supported-science and the instruction-conveyed-science*.

3) Language and assessment:

Sharing and presentation of projects is a key component of the Maker movement, as evidenced by websites such as 'Instructables' and physical 'Makerfaires' that enable Makers to showcase their projects. In the classroom, Maker project presentations supported the need for student assessment. Teachers appreciated being able to gauge students' understanding when students were asked to present their Maker projects to the class. The teachers stressed the value of determining the level of understanding so that topics could be reviewed prior to testing. The presentations were also helpful in cases when school administration visited the classrooms to evaluate teachers' performance.

E. Division of labor:

1) Roles expectations:

The collaboration between the teachers and the design team was initially intended as a mutual partnership drawing on both parties' background and expertise, i.e., the design team in terms of the creation of the Maker materials, and providing support for the Maker activities during implementation, and the teachers in terms of knowledge of the concepts to be taught and the delivery of instruction. In actuality however, all 6 participating teachers saw their roles more as facilitators whose goal was to provide support for the design team to implement the Maker activities during the alloted time in the classroom. This resulted in the Making coordinator, classroom helpers and designers taking on the instructor role as well, beyond acting as support for the Maker activities in the classroom. Over time, roles were adjusted whereby the Making team became the lead instructor during the activity, and teachers took on the role of assisting students in Making tasks, e.g., connecting up the circuit, as well as assisting in classroom management and keeping the lesson plan on track. The teachers also became more engaged in the design process of the Maker materials, as they realized that their greater engagement enabled them to better assist students in the Making in the classroom.

2) Diffusion of knowledge:

The integration of Making into classroom instruction was not possible without the synthesis of multiple threads of knowledge and expertise. These resided in the different members of our project community, the interaction among the members, and the roles they filled in. The technical designers had knowledge of the Making process and technologies, but needed help with the science to be taught and pedagogical approaches to conveying the science. The science teachers had knowledge of pedagogy and classroom management/dynamics and of the science within the confines of prescribed curricula and lesson plans, but lacked the flexibility to conceptualize the science in broader contexts, and did not always understand the science as expressed through the Making activity. The classroom helpers were students from Computer Science, education, or psychology. Depending on their field and the level of study, they had varying degrees of knowledge of Making, science, pedagogy, or classroom management and dynamics. This diffusion of knowledge led to our realization that Making in the classroom necessitated an extremely well-designed, pre-planned and well-articulated process of collaboration and consultation.

F. Rules

1) Explicit rules

Formal rules of the learning system are relevant for Maker activities with regards to: 1) *classroom safety rules* that determine what can and cannot be done, e.g., for safe storage of materials, equipment allowed, etc. One of our designed Maker activities, for instance, required the use of baking soda, and another the use of a hot plate; 2) *class schedules*. The Maker activities had to be designed to fit within the 40-minutes class time, and had to be responsive to the fact that children's activities were fluid and daily schedules were not always followed. Scheduling was also challenging for meetings with teachers as they had fixed structures to work around; 3) *teacher evaluations* in the form of surprise visits from administrators and curriculum coaches. An explicit necessity of the system, these caused inconsistent effects of the Maker activities in the classroom on both teachers and students.

2) Implicit rules

Implicit rules in the system with impact on Maker activities were especially pertinent with respect to *student collaboration rules*. We found that with no clear instructions about explicit roles for each student, students had difficulty collaborating during Making. Oftentimes, one student would dominate the Making, leaving the second student to either actively insist on the chance to participate, or to become distracted and avoid work. Other times, students would request changing partners to avoid having to share or work with a specific peer. While this may not be as significant in workshops and afterschool program settings, classroom Making required each student to have clear, distinct subtasks to do to first, maintain discipline; second, foster collaboration skills; and third, ensure learning.

VII. Discussion and Conclusion

Based on experience data collected from an intensive semester-long study of integrating Making into the elementary classroom, we described themes of importance to researchers, designers, school administrators and teachers using the framework of Activity Theory. The themes we presented highlight tensions and conflicts that arose, but we emphasize that the Maker program on the overall had a highly positive impact not only on children's engagement in learning, but also on teachers' apprehensiveness of instruction outside of the usual rigid structure of the system. Our analysis revealed insights that contribute to the understanding of requirements for the integration of Making into schools: 1) *Teacher's training and self-engagement into Making* and the Maker mindset are of critical importance; 2) *Inclusion of system participants other than teachers*, for instance the curriculum coaches, in the Maker activity design process would be beneficial; 3) Making in the classroom demands *greater flexibility* from teachers in terms of tools used, teaching style, etc.; 4) *Resources on supporting teaching materials* for curriculum-integrated Making are lacking and are not, as of now, readily available to teachers; 5) *Time* is required for teachers to adjust and to see value in the integration of Making; and 6) Making in the classroom is a *systemic activity* by necessity because of the inherent diffusion of knowledge needed. We hope that these insights are useful to the wider deployment of Making in elementary schools, which has tremendous benefits despite being challenging.

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