FUSE: An Alternative Infrastructure for Empowering Learners in Schools

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Abstract: In this symposium, we examine a unique STEM learning environment that is designed to be interest-driven, learner-centered, and inclusive of many different types of learners. The four papers presented here demonstrate the unique features of the FUSE learning environment that empower learners. Respectively, they describe the ways in which this environment allows learners to engage in diverse *learning arrangements* (Stevens, Satwicz, & McCarthy, 2008), enables them to develop and draw on each other's *relative expertise,* facilitates learner agency, and provides learners with a toolkit of knowledge and practices to use in other STEM learning contexts.

Keywords: informal learning, self-directed learning, agency, relative expertise, situated learning

Session summary

The typical organization of classroom activities is familiar to us all; a teacher manages a cohort of children working on a curriculum prescribed by educational authorities; the children's work is tested and graded by the teacher and each child is attached with a record assembled from these grades. Within this organization, children's interests are usually minimally involved, and students have little control of what they do, when, with whom, and how it is evaluated. Furthermore, this typical classroom structure has been argued by many as recalcitrant to true reform or reorganization (Sarason, 1996; Tyack & Tobin, 1994), despite compelling arguments that this particular organization does not lead to learning or at least not to children learning what is intended (Becker, 1972). Other lines of research have documented how difficult it is to change teacher practices and beliefs about student active and self-regulated learning (Meirink, Meijer, Verloop, & Bergen, 2009), and how much work is required to create and support alternative learning environments (Blumenfeld et. al, 1991; Kirschner, Sweller, & Clark, 2006).

In this symposium, we present a multi-faceted portrait of FUSE, an *alternative infrastructure for learning* (Stevens, 2007). The design inspiration for FUSE draws largely on research documenting the effective social and material conditions often found in *out of school* learning environments (Cole 2006; Stevens, Satwicz, & McCarthy, 2008; Bransford et al, 2006). Previous analyses (Jona, Penney & Stevens, 2015) demonstrate that many of the undesirable features of typical classroom activities are largely absent from FUSE Studios (i.e. classrooms in which FUSE is implemented). For example, FUSE Studios are centered around two dozen challenge sequences that 'level up' like video games. Participating students can choose what challenges they want to work on and if and when they will continue with particular challenges, based on their own interests. They can choose to work alone or with peers. They are not graded or assessed formally by adults; instead, using photos, video, or other digital artifacts, they document completion of a challenge to unlock the next challenge in a sequence.

This symposium offers several lines of analysis that document how FUSE is an alternative infrastructure for learning, tied to the ICLS theme of empowering learners. The four papers present brief empirical case studies constructed from ethnographic field data to demonstrate key learning phenomena in FUSE Studios embedded in school environments. All of the papers draw on a shared data corpus collected between 2013-16. The corpus includes ethnographic observations, informal conversations, and whole room and point-of-view video recordings from fifth and sixth grade classrooms offering FUSE for 90 minutes each week (and from selected other STEM-related courses in those schools). The corpus also includes data collected through the FUSE website cataloguing student challenge activity and providing an aggregated picture of student activity across the more than 50 FUSE Studios currently active. The first paper documents key differences between FUSE classrooms and traditional classrooms as learning environments. The second paper documents that students in FUSE develop *relative expertise*—that is, students develop expertise relative to each other through individual patterns of participation in challenges—and come to recognize and rely on the expertise of their peers. The third paper highlights instances of student agency, evidenced by students' spontaneous and creative extensions of FUSE activities. The fourth paper explores the ways learning in FUSE impacts learning in other school contexts. Taken together, these four papers show that the implementation of FUSE is realizing a truly alternative infrastructure for learning in schools, facilitating empowering learning arrangements that are quite atypical of school. This 90-minute symposium will begin with a ten-minute introduction to FUSE. Each paper will be presented for twelve minutes. Our discussant will conclude with a twelve-minute synthesis. Twenty minutes will be devoted to questions from the audience.

Learner choice and the emergence of diverse learning arrangements in FUSE

Lauren Penney, Kemi Jona, and Reed Stevens

This paper explores how FUSE Studios are organized, describing key design elements, the ways these differ from a traditional classroom model, and the types of diverse learning arrangements that emerge. Data in this paper was primarily collected from five classrooms in the 2013-14 school year and the analysis was refined through discussions within the research team about ongoing data collection during the 2014-15 (one classroom) and 2015-16 (seven classrooms) school years.

Learner choice in FUSE leads to the emergence of diverse and productive learning arrangements. Choice, as is the norm in informal learning environments but rare in formal education, is fundamental to the FUSE experience in multiple ways. First, youth participants choose among the current (but growing) library of challenge sequences, based on their own interests. They also may choose to leave a sequence or a challenge at any time. Participants can also choose to work alone or with peers (see Figure 1). And in general, while youth participants are given many resources, tips, and guidelines for completing challenges, ultimately they may choose any course of action as a route to challenge completion. Supporting learner choice in these ways relies on a set of challenge sequences that have been carefully structured to invite initial participation and a website that supports students through successive challenge levels that increase in complexity. The challenge completion process also increased learner choice; rather than the teacher assessing and approving progression, students self-document their challenge completion using pictures or video to unlock next challenges in a sequence. This process frees students to pursue their own interests on their own time frame.

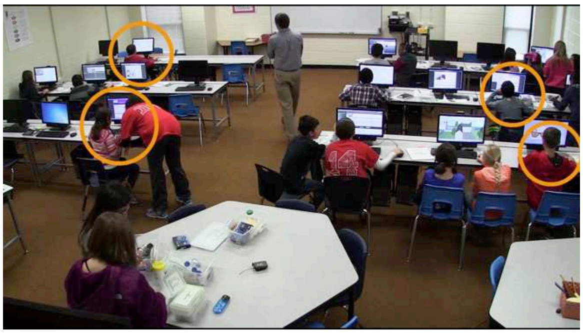

Figure 1. Frames from a video showing diverse learning arrangements in a FUSE Studio, including individual (left) and group arrangements. Both images include numerous student pairs.

In general, the organization of activity in FUSE Studios is a fairly complete inversion of the typical organization of activity in traditional classrooms and thus represents a partial 'alternative infrastructure for learning' (Stevens, 2006). In these typical classrooms, a teacher manages a cohort of children working through the same activities at the same pace from curricular materials designed by corporations and distant educational authorities. Teachers typically instruct from the front of the room, and they tend to be the nearly exclusive source of authoritative knowledge in classrooms. They also define and regulate acceptable activity structures (i.e., group work, whole class discussion, etc.), thus shaping student opportunities for collaborations and conversations (Lemke, 1990). Within this familiar organization of activity, children's interests are minimally involved. And choice is virtually non-existent; students have little control of what they do, when, with whom, and how and when it is evaluated.

In FUSE, students' freedom to choose what to work on and with whom enabled a diverse set of student-initiated learning arrangements, arrangements that were dynamically and fluidly formed, dissolved, and reformed. Figure 2 provides a snapshot of four students' challenge choices across an entire school year. Each dot in this figure represents a challenge level attempt, different challenge sequences are represented through color, and levels are represented by dot size with larger dots representing higher and thus more advanced challenge levels. This data shows that Shruti and Sanika had similar challenge activity (the colors mostly match). During their work on the Jewelry challenge sequence (purple) and the Selfie Sticker sequence (dark green), these two girls sat next to each other and used their own computers and materials to complete the challenges together. This parallel collaboration allowed the girls to access each other as thought partners but did not tie them to working on the same exact artifact. In contrast, Rakesh alternated between many different challenge sequences, often working on multiple challenges in the same day (e.g., the multi-colored dots seen between November and December). He and another student, Vihaan, used the same computer and materials when collaborating to create a 3D model of a car, working to create a joint final product that they 3D printed twice (once for each of them). Finally, Mario's activity also contrasts with the others. He worked on a few different challenge sequences with another student, Dan, before starting Electric Apparel (pink), which he pursued independently and exclusively for the last half of the school year. These and other examples emerged throughout the year, illustrating the fluid and flexible ways students arranged collaborative activity to suit their preferences and needs.

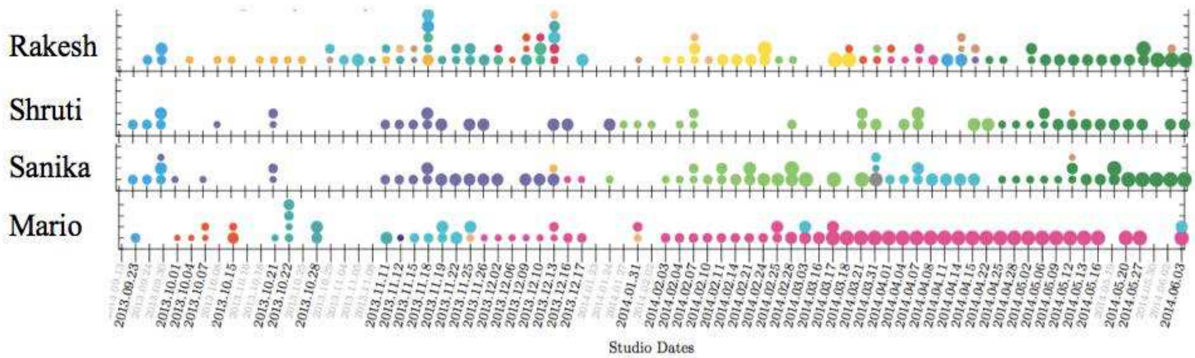

Figure 2. Patterns of challenge activity from four 6th graders during the 2013-14 school year.

Taken together, these examples demonstrate some of the rich diversity of collaborative learning arrangements that emerge from empowering learner choice in FUSE. Two critical design elements of FUSE that foster these collaborative arrangements are: 1) a set of challenge sequences that have been carefully structured to introduce novices to new ideas and support them through more complex iterations of those ideas, and 2) giving students the freedom to choose what to work on, when, and with whom. Removing traditional classroom structures and routines did not result in chaos as many educators often fear. Rather, as students gained experience with FUSE challenges and took responsibility for their own learning, they were learning how to be self-directed, productive, and independent workers. They set their own pace and worked towards goals they chose for themselves. They were learning how to teach, learn, and coordinate work with minimal adult guidance; the very skills Casner-Lotto & Barrington (2006) and others lament are missing from the traditional organization of schooling.

Developing and recognizing relative expertise in FUSE

Dionne Champion, Lauren Penney, and Reed Stevens

Traditional methods of STEM education position the child as a novice and create narrow opportunities for children to demonstrate and constructively utilize their developing skills, related interests and capabilities, perhaps even inadvertently suppressing them (Stevens, 2000; Bevan, Bell, Stevens, & Razfar, 2012; Barron, 2006). Researchers have explored expertise in terms of domain mastery (Ericsson, Krampe, & Tesch-Romer, 1993), developed models for how novices become domain experts (Alexander, 2003), and discussed pathways along which students move in developing science expertise (Schwarz et al., 2009; Alonzo & Gotwals, 2012). Yet we have a limited understanding of young people's developing STEM expertise in real time and know little about how young people *recognize* and *utilize* the expertise of their peers along these pathways towards expertise (Bricker et al., 2008). This paper examines activity in FUSE Studios to expand our understanding of the development and recognition of what we call *relative expertise*, how young people's growing relative expertise becomes valued by teacher and peers, and how relative expertise leads to fluid and varied formulations of peer collaboration, sharing, and assistance. Data used in this analysis comes from two school years (2013-15).

By empowering students with choice about the challenges they want to work on and when they want to move on to something else, FUSE allows differentiated knowledge among participants to accumulate and circulate for many challenges at once, a stark contrast to the lockstep pacing of typical school curricula. This creates an environment of shareable knowledge resources, as different students become knowledgeable with the tools and technologies associated with different challenges at different times and then share that knowledge with one another. Students develop *relative expertise* as they become more knowledgeable than their peers in a variety of challenge-related skills including, for example, connecting LED lights in a parallel circuit, designing CAD files in Tinkercad, or using tools like a vinyl cutter and 3D printer. The following examples show how Anika and Melissa each developed relative expertise based on their different participation trajectories.

Anika, a sixth grader, developed specialized expertise with the 3D printer, and became the resident 3D printing expert in her classroom. After completing a 3D printing challenge, she decided to spend her time in her FUSE classroom helping others troubleshoot their 3D printing issues. She spent months helping her peers in a variety of ways, including helping to prepare their CAD files for printing, troubleshooting and fixing the 3D printer when it malfunctioned, and keeping track of the class 3D printer "queue." Anika even became a recognized resource for adults, giving 3D printing tutorials to teachers and support staff in the building. We see similar patterns of expertise development across multiple students in FUSE. All students become relatively good at something, developing different but overlapping skills. The FUSE activity system allows participants to develop STEM competence by providing a space where they can showcase their newly developing skills in ways that are less "schoolified". Since "not knowing" is not viewed negatively and there is little fear of judgment and no grading in the FUSE classrooms, students are willing to fumble through things on their own or ask for help to develop their competence. Also, there is no disincentive to help others, so students who figure out how to fix or troubleshoot their own issues often offer their help to other students, which reinforces their own developing skills and validates their relative expertise. Students are often publicly recognized as relative experts by classmates or teacher-facilitators who go to them for help or identify them as resources for others.

In this setting of diverse relative expertise, students also learned how to recognize and evaluate the relative expertise of others, learning who to seek out for specific types of help (Hertzog, 2002; VanderBorght & Jaswal, 2009). For example, Melissa gravitated to the Selfie Sticker challenge sequence (creating a graphic design that can be output on a vinyl cutter to create multi-layered stickers) and worked hard to develop relative expertise in that sequence, troubleshooting issues on her own and then answering questions from classmates. When Paulo and Kyree both expressed difficulty starting this challenge, Melissa first assured Kyree "it's not hard, I got it already" and then, after he adamantly refused to believe her, she walked over and helped him through the initial steps of downloading a required graphics template and opening it in the appropriate software program to begin editing it. After this exchange, other students in the vicinity sought her help with this challenge. Later Kyree attempted to help his friends, but eventually requested, "Melissa, come help these girls," reaffirming her relative expertise. Kyree recognized the value of Melissa's contribution to his own progress and positioned her a resource for classmates. As she developed relative expertise on this challenge and others, she freely provided help when requested, even proactively offering tips and pointers to others as she moved throughout the room.

These examples illustrate how FUSE provides students opportunities to collaborate with and value their peers in ways that enable distributed expertise to develop. Unlike traditional school, every student in a FUSE classroom chooses their own path through the challenge sequences, developing a diversity of experiences with various challenges, materials, and tools, and thus developed different sets and varying levels of relative expertise. As they progressed, students began to look to one another as reliable resources, creating an environment in which they could become recognized by peers and facilitators as relative experts. These types of interactions in which peers relied upon one another for their knowledge have been shown to increase self-esteem (Aronson & Patnoe, 1977/2011) and are important for developing a positive identity about subject matter (Cribbs, Hazari, Sonnert, & Sadler, 2015). Our analysis shows that when we design environments that give children the opportunity to develop and share expertise, they often take up that mantle and become empowered learners.

Productive deviations as manifestations of student agency in FUSE

Jaakko Hilppö, Reed Stevens, Kemi Jona, Ruben Echevarria, and Lauren Penney

This paper focuses on exploring three interrelated questions: a) How, and in what kind of situations, do students employ their agency to create new learning opportunities for themselves?; b) What kind of learning situations are thus created?; and c) How are these new learning opportunities play out over time? In answering these questions, we seek to understand the complex interplay between student agency and different kinds of designed learning environments like FUSE.

According to many learning sciences perspectives, one of the fundamental challenges for any educational endeavour is to organize environments which spark and promote the agency of the learners themselves. Participatory learning structures provide the students "the opportunity to decide what they wanted to investigate relative to the presented unit of study, and how they would conduct their investigations" (Siri et al., in press, p.

4). Recent studies focusing on student agency in participatory learning structures embedded within formal instruction suggest how supporting student agency can lead to meaningful engagement among the learners themselves. However, we still lack for accounts of how students pursue their own STEM-focused interests within these environments and take agentive advantage of the learning opportunities offered within them. Understanding the qualities of these opportunities and how they emerge not only adds to the existing learning sciences literature regarding agency in learning, but also paves the way for an accounting of how various participatory learning structures can invite learners to pursue and enrich their own interests.

FUSE provides a rich setting to explore the emergence and qualities of student-created learning opportunities and their development for at least two reasons. The first is student choice as a core design feature. That is, in contrast to conventional classrooms, students in FUSE can pursue and shift between challenges as they wish. Second, FUSE challenges afford multiple solutions and thus provide students with latitude in their how they work. These, and other elements of FUSE studios reflect El'konin's and Vygotsky's (2001) notion of *productive incompleteness* as a precondition for the expression of student agency.

Eteläpelto et al. (2013) and others have noted the complexity of defining agency for empirical analysis. In this study, echoing Rajala and Sannino (2015), we focus on student agency as *productive deviations* that build on, but also depart from the intended FUSE challenge structure. These deviations, when pursued and further developed by the students, represent locally new learning opportunities, originally unintended by FUSE designers in their specific form but anticipated by the general pedagogical design philosophy of FUSE.

We employed iterative interaction analysis methods (e.g., Erickson, 2006) to uncover potential manifestations of student agency in FUSE from a larger ethnographic data corpus of FUSE Studio implementations during 2013-2015. Our analysis has thus far revealed several potential telling cases (Mitchell, 1984) of productive deviations among students in FUSE studios. Below are two vignettes of productive deviations where students build on a particular FUSE challenge, but also depart significantly from the intended challenge design to pursue their own interests.

Example 1: Anna and Leena are working on the third level of the Laser Defender challenge, which involves bouncing a laser light beam through a maze of mirrors. While arranging the needed mirrors Anna and Leena talk with a second pair engaged in the same challenge at the other side of a big round table. The pairs are talking when suddenly the laser of the other pair hits Anna's and Leena's mirrors. A lively discussion ensues regarding how the laser challenge could be made even harder (and in their words thus "cooler" and "more fun"), by asking them to collaborate with another pair or by putting a timer on the challenge. After a short while, the conversation tapers off as both pairs focus on working on their own challenges.

Example 2: While working on Solar Roller, a solar-powered car challenge, a group of five boys approached one of the observing researchers to inquire how they could buy the challenge material for themselves. The students' desire for their own set of materials was driven by the popularity of the challenge and the requirement that each group had to dismantle their car after they had worked on it. This significantly hampered the students' efforts to complete the challenge as they had to rebuild the car each class period. The researcher explained how the students could order the materials and a few weeks later the students brought their own material to the studio. However, rather than just engaging with the existing challenge structure, the students also created their own challenges and experimented with the car in different settings outside the FUSE Studio. *"Now that we actually bought it [the solar roller kit], we actually have the freedom to do whatever we want with it",* Arjun, one of the boys in the group, explained.

Both vignettes show how students in FUSE studios engage with the challenges in ways which expand on the original challenge structure. In the first vignette, the students' actions are inspired by a serendipitous event which incites them to jointly imagine new and harder challenges, quite atypical agency for students in a classroom. In the second vignette, scarce access to the materials leads the students to purchase a car kit of their own and to further explore what they can make and do with the parts. Importantly, the second example seems to represent an even greater degree of agency. That is, not only did the students envision extending the activities, they actually realized this extension. This preliminary analysis suggests that the concept of productive deviations can help us look for how and when learning environments can foster more empowering (i.e. agency realizing) STEM learning experiences.

You *can* take it with you: Empowering learners across contexts

Kay E. Ramey

A central way in which FUSE provides powerful learning affordances is by breaking down the silos of A key way in which FUSE provides powerful learning affordances is by breaking down the silos of traditional STEM disciplines, and engaging learners in more authentic, interdisciplinary, and personally meaningful experimentation and making (e.g., Dewey, 1897; Resnick et al., 2009). Consequently, FUSE activities have the potential to not only motivate students to engage in future STEM learning, but also to provide them with a toolkit of knowledge and practices to use in future STEM learning endeavors (e.g., Vossoughi & Bevan, 2014). However, to understand whether or how students take knowledge and practices learned in FUSE and apply them in other STEM learning contexts, we must follow students as they traverse these boundaries across contexts. The goal of this study was to do just that, focusing on three specific questions: (1) What practices are learned in FUSE; (2) How do learners use these practices in other STEM learning contexts; (3) How is thinking and learning in both FUSE and other STEM contexts contingent upon the sociomaterial conditions of the respective contexts (e.g. Cole, 1996)?

To answer these questions, I observed seven classes of fifth and sixth grade students over two school years, during both FUSE (90 minutes per week) and math and science class activities, identified by teachers or students as related to FUSE. The data presented here are from one class of fifth grade students participating in both FUSE and a tetrahedron kite-making activity in their math class (one hour a day for four days). This kite activity occurred at the end of the school year, after learners had participated in FUSE for a full year. Drawing on cognitive ethnographic methods (Hutchins, 1995), my findings are based on both ethnographic observations of classroom activity and micro-analysis of whole room and point-of-view video, captured by seven focal participants who wore ‘visor cams’.

I observed learners engaging in many of the same collaboration, inquiry, and spatial and design thinking practices in both the FUSE classroom and in the math classroom during the kite activity. In particular, over the course of the four day kite activity, both teacher and students made moves that transitioned the activity system from a traditional math class activity system (beginning of Day 1) – characterized by students sitting in their seats, working individually, and asking the teacher for help – to a FUSE-like activity system (end of Day 1-Day 4)—characterized by learners getting up and moving around, helping each other with questions, and engaging in self-directed research and experimentation.

The teacher’s experience as a FUSE facilitator influenced her instruction during the kite activity, and consequently her students’ ability to engage productively with the activity. For example, during the kite activity, she said she planned to (and did) take a relatively hands-off approach to instruction, more typical of her behavior during FUSE than during regular math class. Rather than directly answering students’ questions, she encouraged them to consult the directions or to do independent research on laptops. As a result, when students got stuck, they studied the instructions, asked each other to share expertise, did independent research (regarding tail and string placement), or engaged in self-directed testing and design iteration. On Day 4 of the kite activity, as students raced back and forth between kite test-flights and an outdoor “maintenance station” where they iterated on their kite designs, the teacher commented on how much more “independent” and “collaborative” the students were than those in past years (who had not had FUSE). Pointing to students modifying their kites at the maintenance station, she noted, “[They’re] helping each other and problem solving, and they’re not giving up as easy.”

The shared characteristics of FUSE challenge work and the kite activity also led students to make their own connections between the activities. For example, during the kite activity, one learner, Aarav, mentioned that making 3D pyramids for his tetrahedron kite was like making pyramids in a CAD program (Sketchup) during FUSE. This prompted other students, who didn’t see this connection to disagree, citing differences between physical and computer-based models. Importantly, during FUSE, Aarav frequently did the Dream Home challenge (a CAD challenge done in Sketchup) and professed interest and expertise in that challenge. He regularly offered other students advice on that challenge, and at one point said, “I only do Dream Home.” It makes sense then that he would see connections between these two activities that other students, who primarily did other FUSE challenges, might not.

Aarav also engaged in at least two productive problem-solving practices during both FUSE and the kite activity. The first, an embodied, spatial practice that Aarav (and many of his classmates) engaged in, was *epistemic object manipulation* (Kirsch & Maglio, 1994). While working on Dream Home, Aarav frequently used the rotate tool in Sketchup to turn his house and view it from different angles. During the kite activity, he also manually rotated his kite, looking at it from different angles, to decide where to attach his string and tail (See Figure 3). The second practice Aarav and his classmates engaged in was sharing expertise. For example, during FUSE, Aarav would frequently ask advice of or offer advice to other students working on Dream Home. During the kite activity, he also engaged in this practice, asking another student for help with a difficult aspect of kite construction (connecting 2D triangles to form a 3D pyramid), and then, later, offering similar help to other students.

Figure 3. Aarav engages in digital rotation of his Dream Home (left) and manual rotation of his kite (right).

Aarav and his classmates provide examples that, through participation in FUSE, students are learning STEM problem-solving practices in flexible ways that allow for their productive use in other contexts. However, as in any case of "transfer," certain things need to be true for learners to move practices between contexts. First, there must be similarities in the sociomaterial conditions of the two activity systems (i.e. opportunities for collaboration; Tuomi-Gröhn & Engeström, 2003). Second, learners must recognize the connections between the two activities themselves (i.e., Aarav seeing connections between Dream Home and the kite activity; e.g., Lobato, 2012). These insights further our understanding of the impact of FUSE on students' STEM learning in other contexts and provide guidelines for educators hoping to aid students in bringing knowledge and practices from FUSE or other informal making and design contexts into STEM classrooms.

References

Alexander, P. A. (2003). The development of expertise: The journey from acclimation to proficiency. *Educational Researcher*, *32*(8), 10-14.

Alonzo, A. C., & Gotwals, A. W. (2012). *Learning progressions in science: Current challenges and future directions*. Springer Science & Business Media.

Aronson, E., & Patnoe, S. (2011). *Cooperation in the classroom: The jigsaw method, Kindle Edition*. Pinter & Martin: Amazon Digital Services. First edition published in 1977.

Barron, B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecology perspective. *Human Development*, *49*(4), 193-224.

Becker, H. S. (1972). A school is a lousy place to learn anything in. *American Behavioral Scientist*, *16*(1).

Bevan, B., Bell, P., Stevens, R., & Razfar, A. (2012). *LOST opportunities: Learning in out- of-school time* (Vol. 23). Springer Science & Business Media.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational psychologist*, *26*(3).

Bransford, J., Stevens, R., Vye, N., Kuhl, P., Schwartz, D., Bell, P., ... Sabelli, N. (2006). Learning Theories and Education: Toward a Decade of Synergy. P. Alexander & P. Winne (Eds.), *Handbook of Educational Psychology* (Second Edition). Mahwah, NJ: Erlbaum.

Bricker, L. A., Bell, P., Reeve, S., Barron, B., Pinkard, N., Gomez, K., ... & Azevedo, F. S. (2008). Mapping the learning pathways and processes associated with the development of expertise and learner identities. In *Proceedings of the 8th International Conference of the Learning Sciences* (pp. 206-213).

Casner-Lotto, J., & Barrington, L. (2006). *Are They Really Ready to Work? Employers' Perspectives on the Basic Knowledge and Applied Skills of New Entrants to the 21st Century US Workforce*. Washington DC: Partnership for 21st Century Skills.

Cole, M. (1996). *Cultural Psychology: A once and future discipline*. Belknap Press.

Cole, M. (2006). *The fifth dimension: An after-school program built on diversity*. Russell Sage Foundation.

Cribbs, J. D., Hazari, Z., Sonnert, G., & Sadler, P. M. (2015). Establishing an Explanatory Model for Mathematics Identity. *Child development*.

Dewey, J. (1897). My Pedagogic Creed. S*chool Journal, 54*, 77-80.

El'konin, D. B., & Vygotsky, L. S. (2001). Symbolic Mediation and Joint Action BD El'konin. *Journal of Russian & East European Psychology, 39*(4), 9-19.

Eteläpelto, A., Vähäsantanen, K., Hökkä, P., & Paloniemi, S. (2013). What is agency? Conceptualizing professional agency at work. *Educational Research Review*, 10, 45-65.

Erickson, F. (2006). Definition and analysis of data from videotape: Some research procedures and their rationales. In J. L. Green, G. Camilli, & P. B. Elmore (Eds.), Handbook of complementary methods in education research (pp. 177–205). Mahwah, NJ: Erlbaum.

Ericsson, K. A., Krampe, R. T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100,* 363-406.

Hertzog, H. S. (2002). " When, How, and Who Do I Ask for Help?": Novices' Perceptions of Problems and Assistance. *Teacher Education Quarterly*, 25-41.

Hutchins, E. (1995). *Cognition in the Wild.* MIT Press, Cambridge, MA.

Jona, K., & Penney, L., Stevens, R. (2015). Re-Mediating Learning. *Proceedings of the 11th International Conference of Computer Supported Collaborative Learning,* Gothenburg, Sweden.

Kirsch, D. & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science, 18*.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist, 41*(2), 75-86.

Lemke, J. L. (1990). Talking science: Language, learning, and values. Norwood, NJ: Ablex.

Lobato, J. (2012). The actor-oriented transfer perspective and its contributions to educational research and practice. *Educational Psychologist*, 47(3), 232-247.

Meirink, J. A., Meijer, P. C., Verloop, N., & Bergen, T. C. (2009). Understanding teacher learning in secondary education: The relations of teacher activities to changed beliefs about teaching and learning. *Teaching and Teacher Education*,*25*(1), 89-100.

Mitchell, C. J. (1984). Typicality and the case study. In R.F. Ellens (Ed.), *Ethnographic research: A guide to general conduct* (pp. 238–241). New York, NY: Academic Press.

Rajala, A., & Sannino, A. (2015). Students' deviations from a learning task: An activity-theoretical analysis. *International Journal of Educational Research, 70*, 31-46.

Resnick, M., Maloney, J., Monroy-Hernandez, A., Rusk, N., Eastmond, E., Brennan, K., ... Kafai, Y. (2009). Scratch: Programming for all. *Communications of the ACM, 52*(11), 60-67.

Sarason, S. B. (1996). *Revisiting "The Culture of the School and the Problem of Change."*. New York, NY: Teachers College Press.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., . . . Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46,* 632–654.

Siry, C., Wilmes, S., & Hilgers, J. (in press). Examining children's agency within participatory structures in primary science investigations. *Learning, Culture and Social Interaction*

Stevens, R. R. (2000). Divisions of Labor in School and in the Workplace: Comparing Computer and Paper-Supported Activities across Settings. *The Journal of the Learning Sciences, 9*(4), pp. 373-401.

Stevens, R. (2007). Capturing ideas in digital things: The Traces digital annotation medium. *Video Research in the Learning Sciences.* Goldman, R., Barron, B., Pea, R., & (Eds.). Cambridge University Press.

Stevens, R., Satwicz, T., McCarthy, L. (2008). In-Game, In-Room, In-World: Reconnecting video game play to the rest of kids' lives. In K. Salen's *The Ecology of Games: Connecting youth, games, and learning.* Cambridge, MA: The MIT Press, 41–66.

Tuomi-Gröhn, T., & Engeström, Y. (2003). Conceptualizing transfer: From standard notions to developmental perspectives. In T. Tuomi-Gröhn, & Y. Engeström, (Eds.), *Between school and work: New perspectives on transfer and boundary-crossing* (pp. 19–38). Oxford, UK: Pergamon.

Tyack, D., & Tobin, W. (1994). The "grammar" of schooling: Why has it been so hard to change?. *American Educational Research Journal*, *31*(3), 453-479.

VanderBorght, M., & Jaswal, V. K. (2009). Who Knows Best? Preschoolers Sometimes Prefer Child Informants Over Adult Informants. *Infant Child Development, 18*(1), 61-71.

Vossoughi, S. & Bevan, B. (2014). Making and tinkering: A review of the literature. *National Research Council Committee on Out of School Time STEM*, 1-55.

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