Let Kids Solve Wicked Problems... Why Not?!

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Abstract: We describe the first iteration of design experiments that aim to assess an instructional framework we call Preparation for Future Collaboration, which consists of three main phases of learning activity: 1) individual cognitive preparation in the content to-be-learned, 2) discussion/collaboration of ideas generated during preparation, and 3) direct instruction. We conducted an experimental study *in situ* in three fourth-grade classes in a public school in Singapore, manipulating the way that students prepared for a collaborative activity in a topic in environmental education. Future analyses will include using measures of student artifacts to assess the effectiveness of different forms of preparation on both the process of learning and post-activity outcomes. In this paper, we share two cases to illustrate student ability to generate solutions to a wicked problem.

Keywords: preparation for collaboration, collaborative learning, complex problem solving

We should put a sensor on the ground so that when someone litters there will be a small space that will open and the litter...will drop into a place with treadmills on the ground and a thin magnetic roof so the cans that have been littered will be attracted by the magnetic roof... when litters are on the treadmill a smart computer can identify the plastic and paper and pick it up with fake metal hands. (Fourth-grade female student and male student, 2015).

Introduction

The above quote comes from two Singaporean students who discussed how to solve a typical wicked problem on waste production and disposal during a class lesson on environmental sustainability. Despite being a highly teacher-centered and assessment-driven educational culture (Hogan et al., 2013), Singapore's education system is shifting towards student-centric instruction. With the shift towards 21st century learning, students should be given opportunities in class to not only apply content that is taught, but to engage in learning activities that involve creative thinking, authenticity, and idea generation. In this paper, we present work from the first iteration of a series of design experiments (Brown, 1992) being conducted in Singaporean classrooms that are founded on a theoretical framework we call Preparation for Future Collaboration (PFC). At the core of PFC is designing individual preparatory tasks that aim to invoke the generation of ideas and naïve conceptions in ways that lead to effective collaborative discussion and learning. We further explicate our framework below, describe the design of our study, and share preliminary findings based on two cases of student collaborative work.

Preparation for Future Collaboration (PFC)

The notion of PFC involves activation of particular cognitive processes through the design of the instructional task, subsequent engagement in peer collaboration, and then teacher-led instruction following. This approach encourages students to freely discuss ideas with a peer, rather than imposing structures on their interactions (e.g. through collaborative scripting or prompting, or training on how to collaborate). We are examining two ways to cognitively prepare for collaboration: a) studying/working with the canonical forms/representations of a topic and b) generating one's own ideas before learning the canonical forms. In both cases, the preparation promotes a different degree of "readiness" for learning in the subsequent collaboration. According to the Preparation for Future Learning paradigm, preparing by generating knowledge promotes readiness to learn in a future lecture by helping students to: differentiate prior knowledge in ways that draw attention to deep principles of the concepts (Schwartz & Martin, 2004; Schwartz, Sears & Chang, 2007), and become sensitive to both the deep structural and surface features of the concepts (Schwartz, Chase, Oppezzo, & Chin, 2011), which then helps to consolidate knowledge during the subsequent lecture. PFC similarly addresses how preparation influences readiness to learn in a future task, however, our interest is in learning in a future collaboration, prior to receiving direct instruction.

The PFC model is theorized across three phases. We borrow from Kapur and Bielaczyc's (2012) work on design principles for Productive Failure to show how the mechanisms of generation, exploration, and consolidation and knowledge assembly spread across the PFC phases, as shown in Fig. 1. Ultimately, our conjecture is that the instructional context drives the learning processes that occur during preparation, which drive the process of collaboration, which affects learning during the direct instruction.

	Phase 1		Phase 2		Phase 3
Instructional context (degree of generative activity in learning tasks) →	*Preparation* (Exploration and Generation)	→	*Collaboration* (Exploration and Generation and Consolidation and Knowledge Assembly)	→	*Receiving Direct Instruction* (Consolidation and Knowledge Assembly)

Figure 1: Phases of the Preparation for Future Collaboration (PFC) approach.

Lam's (2013) prior work investigating different forms of preparing to collaborate has shown similar post learning outcomes from both generative and non-generative preparation, however, the degree of learning during the collaboration differed across the types of preparation (unpublished data). In this paper, we share two cases from the current study to further unpack student collaborative work.

Complex problem solving and wicked problems
According to Funke (2001), complex problem solving has two main features: *connectivity* and *dynamics*. *Connectivity* refers to links between the different variables within a problem, and includes the complexity that each variable entails. Real-world problems (described below regarding our study) can be addressed through a variety of complex solutions, and each solution typically has its own set of interconnected variables. For example, for a problem of excessive waste being produced in a community, a solution focused on reducing waste could stem from individual action (e.g. by producing less, by reusing more, by recycling), which could be influenced by a government policy imposing a quota on waste production, which might encourage communities to organize ways to educate residents about the problem. *Dynamics* refers to the fluctuations that arise within a problem, which signal changes that develop over time. For instance, the solution of a government ban on plastic bags could lead to the long-term effect of producing less plastic waste. However, as communities shift away from plastic bags, there might be an increase in the use of paper bags subsequently increasing paper waste, or a shift towards using reusable bags, leading to the development of a new material. The connectivity and dynamics of such problems often makes them messy, and it is difficult to determine "right/wrong" solutions, thus deeming them "wicked" problems (Hung, 2013). The work on complex problem solving is mostly conducted in older populations (Ventura, 2014; Wickman, 2014). The shift to 21st century learning in K-12 education has emphasized the ability to transfer problem-solving skills (OECD, 2013), and students will be required to engage in complex, real-world problem solving when they enter the workforce (Fournier, 2002).

The present study
Our interest was to investigate how primary school students would engage in complex problem solving, while testing the Preparation for Future Collaboration instructional approach. We designed a problem question that focused on the growing production of waste in Singapore, a country with a great scarcity of landmass. Students were introduced to the problem and given information on the country's space constraints for landfills. They were also presented with the concepts of "reduce, reuse, and recycle," as aids to solve the problem. Students participated in all three PFC phases. We present two cases of student paired collaborative work from the study.

Methods
We used an experimental design to test how two different kinds of preparation would affect collaborative learning and problem-solving outcomes in three fourth-grade classes. The experiment was run *in situ*, and replaced the teachers' original activities for the topic.

Student and school sample
A total of 100 students across the three classes participated. The school was a typical public primary school, and one of the lower ranked schools in its area (1). Our larger project targets low-achieving students, but we have included classes at a range of levels in our first iteration.

Procedure
The PFC lesson was conducted in 1.5 hours. The same researcher facilitated the lessons in all three classes, while 1-2 research team members and the classroom teacher helped to manage the students. Students were first briefed on basic logistics of the study and then listened to a 15-minute presentation by the instructor-researcher introducing the problem question. Students were then randomly assigned to a condition: Select a solution or

Generate solutions. In the Select condition, students individually selected one of three given solutions to the problem and wrote down why they chose the solution. In the Generate condition, students individually generated as many solutions as they could in the given time period. All students worked for 15 minutes during the preparation phase. At the collaboration phase, students were randomly assigned a partner in the same condition. They discussed their individual ideas with each other and then jointly recorded onto a worksheet their "best" solution. Students worked collaboratively for 35-40 minutes. The instructor then engaged students in a whole class discussion by allowing them to share (by volunteering) their collaborative solutions out loud, and afterward presented information about various elements of complex problem solving (e.g., sharing multiple perspectives, complexity/simplicity of solutions, feasibility of solutions, cost-effectiveness, etc.).

Analysis

The larger study will include a post-problem-solving activity that measures problem-solving and transfer outcomes, and we will conduct quantitative analyses of the individual, collaborative, and post-activity measures to compare the two conditional groups. However, here we share two cases of student collaborative work from the generate condition in order to highlight some of the ways that students solved the wicked problem. We present each case of written solutions and our interpretation of the comprehensiveness, novelty, and feasibility of the solutions (2), and also provide excerpts of the student discourse to illustrate negotiation of ideas.

Findings

Case 1:.Our quote above was taken from a pair in a mid-level class. The students also wrote about making "new stuff" out of disposed plastic and reusing paper and they introduce the idea of recycling ash in landfills to "make it into a flower vase and use it as soil." For *comprehensiveness*, this pair's use of details to describe their high-tech solution is noteworthy. They mention a way to handle metal ("cans" being "attracted by the magnetic roof") and using a smart computer to differentiate materials. They describe a "sensor on the ground" to detect trash and using treadmills to transport trash to the appropriate places. In addition, they address what to do with recycled material, such as make "coins" from melted metal. Regarding *novelty*, compared to the other pairs in our sample, this pair's solution was unique. Many pairs mentioned separating the types of recyclable material, but into the existing recycle bins in Singapore. This pair weaves elaborate use of smart technology into their solution. For *feasibility* (that a solution is adaptive to reality), although complex and costly, such a solution is not outlandish. The idea to make soil out of ashes, in fact, aligns to one of Singapore's strategies, in which non-toxic ash of incinerated waste is dumped on an off-shore landmass and covered with a layer of soil to form a self-sustaining green landscape (see http://www.nea.gov.sg/energy-waste/waste-management/semakau-landfill).

The student dialogue included frequent turn-taking and negotiation of ideas, with little to no external guidance to facilitate their interactions. Excerpts are included below:

Excerpt 1	Excerpt 2
S1: The litter will go inside, then go on a treadmill and then *[imitating machine noises]*, all the cans will be *[imitating machine noises]* attracted from the magnetic... S2: How are they gonna do that? How you know, how you know you gonna do that? How they know how to do that? S1: So you must dig the whole Singapore ground. And then puts like a sensor and then every time someone litters... a door open, drop inside. S2: Okay, I think I agree on that also. S1: You agree? S2: Ya, write down.	S1: The waste can be put in— S2: Container. S1: —the landfill. To the landfill— S2: Landfill. S1: —into a landfill or put it in a volcano. S2: What? How can they be transported into a volcano? S1: Cannot ah? S2: Ya. ... *[skipped utterances]* ... S2: Go to, go to erm Indonesia for that. S1: Ya, put it into the Indonesia volcano.

Case 2: In this case, students from a low-achieving class discuss how recycled items can be donated to "poor people" to essentially start small businesses, whereby they remake the items into new things for sale. The students write about donating recycled items to poorer countries so that people can earn money. They also address how they, themselves, can save money by using recycled items to make gifts. In additional, they include the idea that such practices could motivate people to continue to recycle. For *comprehensiveness*, this pair's solution centered on different ways of using recycled materials to earn money for the poor. The level of detail contrasts the first pair, but is still elaborated with several separate ideas (e.g., make "things" to sell; buy food; build houses; buy pencils, books, toys, phone; buy gifts) and the idea of motivation to sustain new practices. For *novelty*, similar

to pair 1, the solution was unique relative to the sample, in particular, with regard to the altruistic focus on reusing recycled material to help the poor or to make gifts for others. Finally, the solution is highly *feasible* because it requires few resources and is a low-cost solution.

Conclusions and implications

Despite the typical highly teacher-centric instruction, i.e., first learning the "right" answers and then applying them to problem questions, our experience has shown that a task designed to first elicit students' naïve conceptions of yet-to-be-learned topics can lead to substantive interesting collaborative work. Our early analysis has shown that grade 4 primary students are capable of collaboratively generating interesting and elaborate ideas to solve a wicked problem, with little teacher intervention or direct instruction on common elements of complex problem solving. In the next iteration of our work, we will improve the design of the learning activities based on initial findings, examine how different types of preparation affect the collaborative process, and investigate how the PFC instructional design influences performance in novel problem-solving activities.

Endnotes

(1) Singapore uses an educational streaming system that relies on student performance on national exams.
(2) These three factors were borrowed from Galati (2015), which provides a comprehensive guide to asses difficult-to-judge solutions to complex problems.

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