The medium is the message: Why a design-based approach produces differential results and fosters scientific reasoning

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Learning by Design (LBD; Kolodner, et al., 2003), is a project-based inquiry approach to science education in which students learn science in the context of designing working artifacts that require targeted science content for their successful design. As such, it capitalizes on the affordances of design activities to foster the development of scientific reasoning, as well as the learning of science concepts. But what exactly are these affordances, and how can they foster learning science? According to Penner, Lehrer, and Schauble (1998), design is a form of problem solving in which thinking and the ability to use tools and materials are reflected in the construction of the artifact. Design, thus, allows learners to have authentic experiences using discipline-specific forms of knowledge (i.e., rough sketches, models, mathematical formulas) and modalities (i.e., defining problems, proposing, testing and evaluating solutions, and, on an ongoing basis, justifying decisions). In the context of design activities, knowledge is viewed as purposeful, fluid, and conditional (Lehrer, 1993).

In LBD classes, design's affordances are supported by culturally sensitive practices, norms and conventions, which develop into action and discourse repertoires that support learning science (Charles, Karkin, Kramer & Kolodner, 2006). Such cultural practices and repertoires, focused around design challenges and situated in the context of science content, give learners opportunities, cognitive tools, and discipline-specific knowledge which allow them to think through and plan what they are going to do, carry out their plans, interpret their results, and learn science in the process.

Briefly, the LBD approach and instructional design, is made up of two action and discourse cycles, consisting of repeated and iterative activities, that we claim are culturally sensitive and support the development of repertoires (i.e., *Messing About, Running Experiments, Poster Session, Rule of Thumb Practice, Pin Up Session, Whiteboarding, and Gallery Walks* activities). The school year begins with a *Launcher Unit*, which engages students in scientific reasoning using relatively simple concepts in the context of relatively simple design (e.g., of a parachute). They move on to the next unit, which engages students in reasoning about more complex concepts (e.g., force and motion) in the context of designing more complex artifacts (e.g., a vehicle and its propulsion system). Each design challenge unfolds in the context of these cultural repertoires. For example, before committing to a design, the class as a whole identifies variables that may be causally related to performance (*Messing About Activity*), and then small groups each select one variable to investigate (*Running Experiments*). When investigation is completed, these small groups make public whole-class presentations (*Poster Session*) of their findings and try to offer a design recommendation based on trends in their data leading to scientific explanations (*Rule of Thumb Practice*). Guided by the teacher, students collectively identify important and generalizable features of and considerations for their designs, which may eventually be linked to recognized scientific principles (*Whiteboarding*). Moving on to designing based on these results, they present and justify their design ideas to the class (*Pin Up Session*), and iteratively getting to working designs, examining the behavior of artifacts they design, helping each other explain (*Gallery Walk*).

We present a case study of one class of middle school physical science students engaged in an LBD approach – second year of a three-year NSF funded research project investigating the development of scientific reasoning in middle school. Data from written reports, performance assessments, pretest-posttest, and videotapes show significant improvements in students' scientific argumentation capabilities and skills, as well as their science content knowledge. Contrary to the literature on scientific argumentation (e.g., Driver, Newton, & Osborne, 2000), our results show that LBD students, early on, begin to engage in such reasoning as part of the "natural" discourse practice in the public accounting for design recommendations (i.e., in poster sessions and pin up sessions). Additionally, we see a significant improvement between pretest and posttest scores[1] on an adapted version of the Force Concept Inventory questions (FCI: Hestenes, Wells, & Swackhammer, 1992). Though we make no claim that the all use of science concepts is without what is often characterized as "misconceptions" (i.e., conceptual change theories aside), Clearly, our results suggest that LBD's instructional design has done something "right" in regards to supporting learning science in the context of design.

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[1] A paired *t*-test between pretest and posttest for all 82 students. There was a statistically significant increase in total scores from pretest (M = 10.13, SD =1.98) to posttest (M = 20.39, SD = 3.64), $t(81) = 23.04$, $p < .001$. Of note is the low correlation between pretest and posttest scores, $r = .06$, $p = .574$).