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Design Principles for High School Engineering Design Challenges: Experiences from High School Science Classrooms

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At the University of Pittsburgh, we have been exploring a range of approaches to design challenges for implementation in high school science classrooms (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Ellefson, Brinker, Vernacchio, & Schunn, 2008; Schunn, Silk, & Apedoe, in press). In general, our approach has always involved students working during class time over the course of many weeks. So, our understanding of what works must be contextualized to that situation (i.e., without significant home support, by students enrolled in traditional classrooms, involving content that is connected to traditional science classrooms). However, our approach has been implemented with thousands of students in over 80 classrooms ranging from 9th grade biology or general science to 11th grade physics, from traditional mainstream science classrooms to elective Biology II or Honors Chemistry, and from high needs urban classrooms to affluent suburban classrooms. In other words, there is some important generality to these experiences. We have also conducted a number of studies on students in these settings, to understand a range of factors that influence student learning and affect outcomes (Apedoe & Schunn, 2009; Doppelt & Schunn, 2008; Reynolds, Mehalik, Lovell, & Schunn, 2009; Silk, Schunn, & Strand-Cary, 2009). This white paper provides a brief summary of principles that appear to guide successful experiences for students.

1) *Design challenges (in science classes) should involve particular systems that naturally emphasize key science learning goals from those classes.* In order to have a rich design experience in which students experience deep connections between science and design as well as allow for the time to seriously engage in iterative design, the time spent on the design challenge must also do science instructional work (i.e., students must learn some science, and preferably traditional focal science content rather than 'bonus' concepts). But engineering design naturally involves some creativity / multiple solution paths. How does one insure that the design challenge stays on target toward the goal involving conceptual learning targets? We have found that a systems design approach helps to achieve this goal while at the same time teaching key engineering processes (subsystems decomposition) and concepts (systems concepts). For example, to teach key thermodynamic concepts in chemistry class (i.e., the relationships between chemical structure, chemical transformations, and energy) we had students design chemically-based heating or cooling systems. In order to make progress on such systems, students needed to learn key big ideas in chemistry, regardless of which kind of system they wanted to design (e.g., a headband that cools them on the dance floor, or a therapeutic blanket that heats athletes, or a heated toilet seat). To teach biology students about the central dogma in biology, we had students create expression systems involving genetically modified bacteria that expressed key features under certain environment situations (e.g., turn blue when the loofa is too old, or turn blue when too many people peed in the pool). To teach environmental science students about ecosystems, we had students design a natural filtration system to address pollution problems (e.g., a water filter system for drinking water while climbing).

2) *Design challenges should allow for some flexibility in choice of target goals*. Many design challenges involve very fixed targets, such as the FIRST robotics competitions. This approach requires that all students 'buy in' to the same design, whereas student interests vary and the same challenge is not equally motivating to all. In addition, having a fixed challenge creates performance goals (do better than others) rather than mastery goals (improve ones own skills and knowledge), whereas mastery goals tend to produce better learning outcomes in the long run and are motivating to students across a wide range of skills (Elliot, 2006). Allowing students to pick their own goals (within some reasonable range) increases situational interest, creates more mental connections between engineering and personal interests, and allows students to maintain mastery rather than performance goals.
3) *Design challenges should involve helping others*. When students pick their own design challenge, they can pick from a very internal perspective (e.g., locker alarms, touchdown detectors) or they can choose to help others (e.g., grandmother's pill reminder, modified hairbrush for physically disabled adults). While some students will quickly consider the needs of others, many students require a prompt to go there (e.g., some reading materials about particular special needs populations, or field trips to particular settings such as nursing homes). When students focus on the needs of others, it is more natural to conduct research to quantify the engineering requirements, and the gratification of a job well done is even greater. Further, when students see that engineers solve real problems in the world, they become more interested in engineering careers (Reynolds, et al., 2009).
4) *Larger design challenges should be divided into subsystems*. Just as the early airplane designers struggled with the high cost of failure of whole airplane designs and the Wright brothers succeeded by breaking the difficult problem set into much more doable subsystems, students also benefit in may ways by being pushed to tackle individual subsystems in isolation and in sequence. This approach models some systematicity to the design processes and allows for more successful final products given limited design time. Incremental successes are more motivating than failed designs. Further, they provide support for students without overly scripting exactly what solutions are tried or exactly what process steps must be completed.
5) *Requirements documents set high expectations*. Students naturally get tired or bored with an extended design challenge at various points during its resolution. It is easy to consider the first or second solution 'good enough' and not seek to consider any further revisions, although those revisions are needed to push their design and science thinking. By starting with the creation of a requirements document with high 'real world' expectations, students are motivated to keep at the design challenge to meet the goals they set themselves, in addition to seeing the importance of design processes in solving real problems.
6) *Design challenges should require reflective presentations rather than just the construction of prototypes or demonstrations of prototype functionality*. Many students can get conceptually lost in the current design if the design itself is the only deliverable, forgetting to consider what design path was followed, what strategies were more successful, or why certain designs were less successful. The reflective designer learns more from the design process about the design process and about the factors underlying the successful design. Document requests along the way can be easily ignored as superfluous during an authentic design challenge. But when the documentation is a natural requirement of the final deliverable, then students are more likely to engage in real reflection. In one form, we have design symposia, in which students make and present posters that describe what the solution is, how it works, and the

process by which it was produced. In another form, students turn in mock patent applications, which require descriptions of the design, how it works, and evidence of systematic testing to show that it works. In a related fashion, we have found it useful for reflection to require intermediate presentations at natural design points (e.g., of requirements documents, of decision matrices, of early prototypes).

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