Analyzing Materials in Order to Find Design Opportunities for the Classroom

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Abstract

Challenged with introducing design activities into their STEM classes, K-12 teachers now must deal with a variety of materials (such as toolkits for STEM design activities) that need to be assessed and then modified to address the demands of the new standards. We briefly analyze a simple design task in order to show how fundamentals of design concepts and practices can be more explicitly and productively emphasized. We present guidelines for teachers to use in assessing and modifying STEM materials to make them rich opportunities for students to learn about design as a complex and powerful problem-solving process.

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Design and its introduction to both teachers and students

For K-12 science and math teachers, technology and engineering have always been relevant topics, albeit typically of a tacit or peripheral nature. Often teachers either purchased technology or constructed an apparatus from the technologies at hand and then employed it to demonstrate an application of a scientific principle, perhaps describing the behavior of the apparatus mathematically. For example, firing a projectile at a falling object in order to demonstrate that both are accelerating downward at the same rate (in the case of the projectile, neatly along the path of a parabolic arc). The focus was on the science and mathematics aspects of STEM, rather than on the properties of the technology or how to construct it.

One reason for this emphasis on the science and mathematics over the design may be that scientific theory testing and mathematical generalizability are regarded with more respect in an academic context. In schools, design might be viewed as having the lower status of "empirical application." In the example of the projectile and falling object, a demonstration of the principle that makes the surprising but accurate prediction of falling and projectile objects colliding may seem more fundamental than having students consider how to aim the projectile initially for a consistently successful collision of the two (i.e., an application of the principle). The demonstrator tinkers beforehand until the demonstration performs consistently, but does not really discuss the significance of that coordination effort with the students. The most basic aspects of design are not discussed because these may be complex, messy distractions that students will find hard to understand.

Another possible reason for this emphasis on the abstract and general over the application aspects of the design might be that the analytical aspects of science and mathematics (which are often considering challenging to most) might actually be more accessible than concepts or processes of design. Analyzing idealized scientific principles might seem easier than instructing students on the messiness of how to create the equipment used to generate the data that is needed for the analysis.

Whether the reason for privileging analysis over design is one of ease or one of relative importance, K-12 teachers are now facing a challenge of making design more visible and central to their students. Interestingly, this situation is similar to what had occurred in engineering higher education of the recent past. Analysis had supplanted design for years, and during the 1960s – 1990s undergraduate engineering curricula had become predominantly theory driven (Nicolai, 1998; Seely, 1993) to the detriment of learning about design and application. Because an undergraduate engineering degree is a professional degree that should produce individuals who can enter the engineering workforce, many key representatives of the engineering professions protested this state of affairs. These protests led the National Science Foundation (NSF) to fund multiple research projects about what design is and how experts use it. Later, the Accreditation Board for Engineering and Technology (ABET) revised their standards toward including design in undergraduate curricula. The result is that design, especially when done collaboratively in teams, has indeed become a staple of engineering higher education (Lattuca, Terenzini, & Volkwein, 2006).

The engineering professions demanded that higher education provide experience with design, and so administrators designated a place for design in their curricula and instructors made the necessary changes to include design activities in their courses. Those events reveal two reasons design is important enough to address with K-12 students as well. Firstly, engineers are expected to perform design as a significant portion of their professional careers, and K-12 students should be exposed to the authentic nature of engineering in order to make informed decisions about their undergraduate study and career choices. Secondly, now that engineering undergraduates are expected to engage in the practices of engineering via the curriculum, K-12 students with little prior exposure to design activities will struggle more relative to peers who might have already developed basic design skills.

Interestingly, the performance expectations for design in K-12 classrooms have many similarities to those in higher education. However, there are some significant differences in the situation of K-12 and university engineering programs that need to be addressed. Teacher experience with design as an explicit focus of instruction is at the head of the list. At the most basic level, experience in engineering design cannot be expected from K-12 teachers who never had to learn it or teach it. While it is reasonable to expect that lack of preparation will change in the near future through various pre-service and in-service professional development opportunities for new and existing teachers, we propose to accelerate the process with our guidelines for evaluating and revising design-related materials for K-12 classroom use.

Before we present the guidelines, we begin with making a case for why they are worth considering. Firstly, we describe some basic competencies associated with design at a nitty-gritty level that may be more understandable and concrete than the more vague standards statements that currently exist. Then we walk the reader through how we analyze a design task to assess whether it aligns with a subset of these competencies. We start with a design task that we anticipated would help students learn and demonstrate these competencies. On closer inspection, we identified limitations in the implementation of the design task that likely impeded students' abilities to attend to these competencies. We do not go into all the details regarding the design task and its administration because it is not the goal for this chapter to have teachers implement this particular design task with their students. Instead the point is for K-12 teachers to have an example of how to structure a design task in ways that foreground design concepts and processes.

Finally, with this concrete example in hand, we present a tabulated set of guidelines for K-12 teachers inexperienced with design instruction. Use of these guidelines might support initial evaluation of materials in terms of selecting ones that already have useful properties for teaching design as well as determining where materials could be further improved.

The range of design competencies

Due to the expanded mathematics goals in the Common Core State Standards Initiative (2011), and the expansion in the Next Generation Science Standards (2012) to include engineering design competencies, K-12 teachers need to find, create, or adapt classroom activities related to those competencies. By design competencies, we refer to the following, described in terms that highlight the social and societal aspects of design practices:

- recognizing ill-structured and ill-defined conditions that are found unsatisfactory by some specified population (concept of problem finding)
- conjecturing about the limitations and resources that affected problem-solvers have at their disposal (concept of problem scoping)
- analyzing the preferred conditions of the various stakeholders in that population (concept of problem defining)
- deriving the range of problems that could be addressed since different stakeholders see different problems (concept of problem refining)
- synthesizing paths to bridge from existing to preferred conditions (process of exploring solutions)
- evaluating the consequences of these paths in terms of effects on different stakeholders (process of evaluating solutions)
- iterating possible versions of a path in order to refine or otherwise improve it (process of improving solutions)
- throughout the design process, working collaboratively in order to exploit multiple sources of expertise, such as expert provided critique (processes involving collaborative skills)
- communicating one's conceptualizations of problems and possible solutions in order to elicit feedback (processes involving communication skills)

We include this list (derived from Appendix I – Engineering Design in the NGSS, 2012) to identify potential areas on which to focus when considering how to analyze and improve design-related materials. The list is not exhaustive and excludes various other design concepts and processes or “Learning and Innovation Skills” such as critical thinking, communication, collaboration, and creativity (Partnership for 21st Century Skills, 2011). Indeed, because of the expansive nature of design, many teachers will need to revise their beliefs about the range of content that could be considered engineering and design.

The next consideration should be to identify when and in what ways to incorporate design productively in learning and instruction. Design is often resorted to when *resolving* ill-structured and ill-defined problems. Note that there is a clear distinction between solving and resolving, in that ill-structured and ill-defined problems are not really solvable to the extent that there is a unique solution and that such a solution can be reached in a prescriptive linear manner (Rittel & Webber, 1973). For example, by contrast, x+3=8 has a clear single solution, and an experienced problem solver in Algebra I knows exactly how to start solving such a problem. Instead, design typically requires multiple iterations in order to educe and refine its possible directions (Günther & Ehrlenspiel, 1999; Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, & Ryan, 2003; Louridas, 1999; Schön, 1992).

The ill-structured and ill-defined nature of design permeates all of the design competencies that we have identified, from problem finding through to communicating solutions. Even an experienced designer does not know how to start applying a design process in order to make sense of a wicked problem except by taking a stab based on “theoretical interests, the special problem under investigation, his conjectures and anticipations, and the theories which he accepts as a kind of background: his frame of reference, his ‘horizon of expectations’” (Popper, 1957, p. 172), nor how to end except by satisficing (Simon, 1957). As a result, problem framing, exploring alternative solutions, and getting feedback on ideas are all critical aspects of effective design.

As a consequence for teaching, the complexity and messiness of design means that design processes do not lend themselves either to being modeled in simple analytic terms (i.e., always follow these simple steps; Lesh, Hoover, Hole, Kelly, & Post, 2000) or to being parsed as traditional learning objectives. Our goal is to show how it may be possible for teachers to embrace the ill-structured and ill-defined nature of design in how they understand and implement design activities in their classrooms.

Preparing to teach design: A way of teaching, not just a thing to teach

After a few years, K-12 teachers have knowledge of how to teach, they have knowledge about content with which they are familiar, and they have knowledge about how to teach the content with which they are familiar (pedagogical knowledge, content knowledge, and pedagogical content knowledge, respectively; see Davis & Krajcik, 2005). All this knowledge was hard won through gaining experience and tapping expert advice, as is the case for any profession. Since most K-12 teachers have little or no expert guidance, the aggregation of knowledge of design concepts and processes and how to teach them may be daunting. In short, if K-12 teachers have not previously thought about teaching design, how do they even know where to seek advice?

We propose that resolving the challenge of introducing design activities requires development of teachers' awareness about using design as a reactive pedagogy, a kind of augmentation of their pedagogical content knowledge. By reactive design pedagogy, we mean an iterative give and take between teacher and student as a conversation that explicitly examines the nature of the problem being addressed, the process being used to address it, and the concepts being developed through that process. It is a questioning of the expertise that the students are bringing to bear. For example, a reaction to a student's presentation of a problem description or possible solutions might include suggestions for avenues that have not yet been considered. The student presents an interpretation of the situation at hand, and the teacher reacts, providing material for the student's further reflection about resolving the situation or problem. A reactive pedagogy is critical in design instruction because the nature of design cannot be reduced to a series of linear steps that when applied work progressively toward a well-defined goal. Instead, rich experiences in design learning are more likely to result when there is explicit support for students to consider multiple, alternative possible ideas, to utilize both forward and backward reasoning, and iteratively refine their understandings and solutions.

Reactive design pedagogy requires teachers to maintain conversations with their students about content, process, and result. That does not mean the target design competencies are treated in a haphazard manner, but rather that the sequence of encountering and mastering solution paths and competencies will probably vary from class to class or student group to student group. Teachers have to be prepared to react to those differences, whether by steering the conversation (e.g., getting back to the target design concept or design practice) or allowing it to take its direction and then analyzing the unexpected results in order to determine why they occurred. As such, teaching using design places responsibility on both students and teachers, who will need to master dealing with both ambiguous situations and the unexpected consequences that arise from their interventions. With that in mind, we next describe a design task to illustrate the limitations of a task as given; along with how the task might be altered using reactive design pedagogy in ways that explicitly foreground and support development of design competencies.

A simple example design task: The block tower task

In the analysis done for this section, we do not present all details of the design task itself or exactly how to fix all aspects; instead we focus on the opportunities for reactive design pedagogy that the task could provide. We also call attention to an aspect of the task that we had not anticipated—the production of a fundamental design discourse that we were not prepared to react to or exploit. The example is followed by guidelines we delineate for how a teacher deliberating about the use of this task could have analyzed it and refined it before deploying it.

The *block tower task* involved stacking wooden blocks in order to make a tower. Middle and high school students participated in the task in teams of three or four, either during a science fair or as part of a summer enrichment program. Each team of students was given approximately 50 blocks (1.5 cm x 2.5 cm x 7.5 cm each) and the student teams were to stack the blocks on a platform (12 in x 12 in) that would shake when activated. A trial was defined as successful if no blocks were vertically displaced during 20 seconds of shaking. Students could make as many trials as they wished within a 20-minute time limit, and the team that made the tallest tower that withstood shaking was declared the winner.

As background resources, every team was also provided with a set of short documents that emphasized five features block towers might have. Each of the features had two distinct levels: *internal density* (hollow or solid), such that hollow towers had fewer internal members than solid ones did; *shape* (pyramidal or rectangular), such that pyramidal towers were wider at the base than at the top, while rectangular towers were the same width at both top and bottom; and symmetry, location on the shaking platform, and stacking patterns of block layers. Figure 1 shows a block tower with hollow and rectangular features.

FIGURE 1. Example of block tower before shaking.

We explored the use of two different guidelines given to student teams to test their effects on how successful student designs were and what they would learn from the design process. Teams in the *individual features* group were encouraged to focus on the effect of one feature of a tower, the implication being to conjecture how the feature contributed resistance to shaking (although the feature being considered was allowed to vary from trial to trial), and how to take advantage of the feature over a series of trials in order to make a taller tower (VOTAT or varying one thing at a time, per Tschirgi, 1980). We thought this strategy would improve student learning of factors that influence the success of a tower.

For the other treatment, the *systems of features* group, teams were encouraged to examine how combinations of a tower's features affected shaking resistance in each trial (the combination was allowed to vary from trial to trial). This process is a variation on HPTC, or "holding particular things constant," (Apedoe & Schunn, 2009) in that the teams in this group were encouraged to consider interactions among block features rather than establishing one on which to focus. We thought this strategy would improve the efficiency of finding a very successful solution.

The design task was one that professional engineers would classify as non-trivial: side-to-side shaking is a dynamic lateral loading for which computer-aided analyses would likely be employed. It is also important to note that both VOTAT and HPTC can be of great value to professional engineers modeling structural systems, with each approach having a particular advantage depending on the situation. It turned out that neither approach on its own was sufficient to support students' engagement in sophisticated design concepts and processes in this design task implementation. One issue was that the affordances of the materials and the setup made it difficult for students to make intuitive conceptual connections between the features that were identified in the support materials and the performance of their designs. After all, how should students have approached the task without the experience or computational resources of professional engineers?

The students first had to find a structure that would resist the applied stresses before they could use strategies to modify that structure for comparison. The students used what they had previously understood about structures, and several teams attempted to apply the easily recognizable premise of leaning blocks against one another to make triangles and tetragons, assemblies which they knew would normally resist deformation. Teams spent a lot of their 20-minute time limit arguing about how to make sense out of the task constraints: lateral loading that does not act like gravity, coupled with being given a structural technology that is fundamentally ineffective at resisting the loading. In short, instead of facilitating observation of how students adopt and modify analysis strategies such as VOTAT and HPTC, we presented a phenomenologically-baffling situation for students to deal with in a very short period of time.

What the block tower task almost did: Reveal student design practices in discourse

A reactive design pedagogy would call for modifying the task in ways that would provide more support to the students to engage in authentic aspects of design. In particular, the task could have been structured such that students engaged in a discourse that eventually would have enabled them to deal with the problem through increasingly sophisticated processes and concepts.

To promote rich design practices, a design task should involve a *wicked* problem (Rittel & Webber, 1973)—no fully-specified statement of the problem, no single best solution, no well-defined stopping rules or set of permissible operations, no straightforward guidelines on solution directions. The block tower task required students exhaust the assemblies of braced frames they were familiar with (triangles and tetragons), and to start ideating and iterating after failures – in other words, to resort to design as a way of dealing with the unknown. The task was not, however, an entirely wicked problem because the mission of building the tallest tower that withstood shaking was a definitive problem formulation and there was a clear criteria for a winner.

The winning team constructed their tallest tower with a hollow interior that allowed for slight lateral displacement of individual blocks as part of a non-rigid unbraced frame (similar to that in figure 1). Post-interviews with the students revealed that their tower frame's lateral load resisting attributes were unintentional, and that the students had no vocabulary to describe why their tower worked. This lack of relevant language was fundamentally limiting to what students could learn and how teachers could guide them. But the students did have an artifact as a starting point from which to develop an intent and then communicate it. The getting started by doing something to be the object of critique, is in and of itself, a non-trivial design event and a crucial component of design thinking. Design thinking values communicating a concept as an elicitation of others' expertise in a discussion – a design conversation – demonstrate an effective reactive design pedagogy.

While students did not initially have a vocabulary for describing design concepts, they were beginning to develop one (primarily of shapes and secondarily of words) around this task. Gubrium and Holstein (2000) place an important distinction between discursive practice (the real-time structuring of a reference to a concept or object under scrutiny) from discourse-in-practice (recognition of the boundaries within which that structure's components may be drawn and assembled). The creation and modification of towers engaged students in a *discursive practice* related to designing, pushing them to come to terms with a *discourse-in-practice*. In the situation of the block tower, discursive boundaries were not yet apparent to students at the beginning, but become accessible to them as a consequence of initiating the discursive practice for which the creation of an artifact (or, more correctly, a succession of artifacts) is necessary (Engeström, 1987; Hewitt & Scardamalia, 1998; Krippendorff, 1989). By developing a discourse for describing their design, the students were learning how to design: confronting a wicked problem, choosing a way to make sense of it, and framing approaches to dealing with it.

Strategies that could improve the discourse during design

To reinforce reactive pedagogy, the design task could encourage students to reflect on their processes by explaining them to someone else in the form of a decision tree. Here the students also benefit from analyzing the audience's reaction to the presentation of the decision tree. Recall that, "decision-based design cannot account for or suggest a process for how concepts and alternatives are generated – and this is often regarded as the most creative and hard-to-model aspect of design thinking" (Dym, Agogino, Eris, Frey, & Leifer, 2005, p. 107). A decision tree cannot sufficiently describe all aspects of design process but rather: following a trail of decisions in a structured way leads to conversations about why and how students made those decisions and what the consequences are from, say, not following alternative paths.

Sara and Parnell (2004) describe a critique process, which can be thought of as another kind of design conversation that challenges and hones students' development of productive discourse about design. This process involves the use of outside critics who are invited by the teacher to the class (e.g., a practicing engineer). "Students present their work visually and/or verbally to a panel that might include tutors, visiting critics and fellow students, in order to receive feedback. Through this dialogue, a useful learning opportunity is created for the whole group, and in particular, students are expected to learn valuable lessons that can be taken through to their future work. In this way, reviews provide the opportunity for reflection on the project; the processes that the student used and the finished product," (p. 57). With regard to possible critique strategies, Kolodner et al. (2003) outline a number of effective options ranging from in class pin-up sessions to public presentations that are used in their middle school curricular units.

It should be noted here that critiques do require some preparation in order for students to get the most benefit from them. Students need to understand the function of their artifacts as vehicles for eliciting expertise and to treat the critique process as a way of garnering others' expertise in order to expand and augment their own catalogs. Even though the critical reaction from either a teacher or an outside expert is crucial to teaching design, it is not as common a feature of other pedagogies, and can require some getting used to by everyone involved, in order to promote a productive dialog.

Interpreting design opportunities: How the guidelines we present here can benefit teachers

We return to the main question: How do K-12 teachers find new ways (or modify existing search strategies) to incorporate engineering or other design activities in the classroom? We reviewed what happened with our block tower task with teachers in mind. We thought about how we would have better facilitated useful design discursive practice in students. The design task allowed the creation and manipulation of an artifact. This is a core element for encouraging student-generated design activities and concepts as a means to reach a relatively sophisticated engineering discourse-in-practice that could serve as the basis for a reactive design pedagogy. The guidelines below present more suggestions for aligning classroom materials with the range of competencies that were discussed earlier in this chapter.

The guidelines refer to the block tower task but can be applied to most examples of design tasks. We have divided the guidelines into two tables: the first table deals with design concepts and the second table with design processes. Design concepts can be applied *to things to make* and design processes can be applied *to ways to make them*, with an understanding that not all things to be made are necessarily physical artifacts (e.g., sometimes processes or services can be designed).

Example modifications of materials to support particular design *concepts*

The materials for a design task can be sequenced in a classroom in order to progressively produce three kinds of concepts: design models, user models, and system images (to act as interpretive vehicles between the models). Norman (1990, p. 16) connects the designer's problem-solving and user considerations in terms of the problem of different models or representations:

> The *design model* is the designer's conceptual model. The *user's model* is the mental model developed through interaction with the system. The *system image* results from the physical structure that has been built (including documentation, instructions, and labels). The designer expects the user's model to be identical to the design model. But the designer doesn't talk directly with the user -- all communication takes place through the system image. If the system image does not make the design model clear and consistent, then the user will end up with the wrong mental model. [emphasis in original]

Visualization is a recurring challenge in design that involves many underlying concepts for students to identify and tackle. There is a frustration that presenters often face during a critique, when backgrounds for presenter and reviewer do not align sufficiently for optimal communication. There is also the consideration for third party users of a design concept, who will not have the designer on hand to explain the concept.

TABLE 1

Suggestions for Modifying the Block Tower Task for Design Concept Emphasis

Concept addressed	How this relates to the current block tower task	How the block tower task could be made a stronger example of the concept
systems consideration by zooming in and out at various scales and scopes in order to address: systems, subsystems that are components of systems, super-systems of which the systems are a part, system boundaries, and contextual extra-systems outside a given system's boundaries (problem finding/scoping) **possible examples in NGSS:** **HS-ETS1-3** **Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.** **HS-ETS1-4** **Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.**	currently missing: context adjacent to blocks is not considered	• provide additional structures that could be affected by block failures and award points for maintaining block failures within building footprint, even if members shift vertically
	currently missing: whose need is being addressed by this investigation is unknown	• search for whose need is being met by a new built form, • analyze needs, resources, and constraints (any or all of which may be revised later) • distinguish needs from measurable requirements and solutions
	currently missing: physics intuitions are not leveraged – novice participants do not have previous experience with lateral forces and are not allowed to modify blocks to attempt resisting lateral stress	• allow modification of blocks • provide tools to perform modification
	currently missing: no supporting tools for reflection on design idea performance – although function is known and structure is by default limited to compressive stacking, behavior of the built form is indeterminate and indeterminable beyond the affordances of a massing model (crude sketch model intended to show how the shape and proportions of the overall building result from its larger and smaller volumes in relation to one another)	• storyboarding with regard to smaller scales of detail and intermediate scales of human interaction (not to be finalized, but rather discussed in passing with the intent of establishing relationships across scales and then returning for another pass later on)
alternatives to familiar phenomena (problem finding/defining, exploring solutions) **possible example in NGSS:** **MS-ETS1-1** **Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.**	currently missing: making sure novel elements are salient – clues about unfamiliar phenomena (such as lateral forces) that are being introduced, and how to deal with them, because one cannot index and retrieve strategies that one does not already have	• distinguish lateral stress from gravity • lead students to consider that there might be unfamiliar stresses in addition to gravity

Rosson and Carroll (2009) describe another set of concepts that teachers might employ to engage students with the users of the design and other stakeholders in wicked problems in order to facilitate this communication challenge. Students can be helped to recognize people just like them or resemblances among folks in families or communities doing things similar to what the students might do. Other variations can also work; in fact, even the exact opposite strategy can work, as long as students are asked to make an explicit comparison of how others are different from them. In all of these approaches, the ability to communicate design thinking in ways that push the design forward is what the teachers are helping students to develop.

Examples modifications of materials to support particular design *processes*

The term *design* can refer either to the concept being formulated (design as a noun) or to the formulation itself (design as a verb), but there is an important deep connection between the two during learning. In particular, we think more attention to the rules given in the design task and allowing some breaking of rules can be powerful for allowing better design content and better design process.

When implementing the block tower task, we often imposed constraints on the participants with respect to: individual features and systems of features, how to classify each of those, how much time the platform shook, and when the time for the task had expired. Additionally, there are other critical design procedures associated with the block tower task that we have not yet discussed: the ones students themselves individually impose upon the problem, and the ones generated by having to work with one another.

Dealing with those in turn, we start with constraints that students themselves imposed on the task. Never did we tell the participating students that they could not scratch up the block surfaces

TABLE 2
Suggestions for Modifying the Block Tower Task for Design Process Emphasis

Practice addressed	How this relates to the current block tower task	How the block tower task could be made a stronger example of the practice
iteration, both as refinement of a single approach and as development of multiple concurrent approaches to the problem (evaluating/improving solutions, collaborative/communicative skills) **possible examples in NGSS:** **K-2-ETS1-2** **Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem.** **K-2-ETS1-3** **Analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.** **3-5-ETS1-2** **Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.** **MS-ETS1-3** **Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.**	currently missing: expert and peer social drivers of refinement—there are no experienced designers as participants, such as those from outside the classroom	• include a participant whose zone of proximal growth is only a little more advanced than those of the other participants in order to derive some advantage from reciprocal teaching • what to create for a critique and how to steer it toward tapping critic expertise • how to recognize unanticipated critique value • how to sift what students receive from critics in order to separate what is to be kept as useful
	works as an example: experiential drivers of refinement – generating ideas, recording them (although not for participant use), and iteratively testing them	• making video available in real time for analysis • providing external memory storage/retrieval for consultation
	currently missing: material selection as presented to students is overly constrained	• if a variety of materials were allowed, they could be chosen for an iteration, fixed for that iteration, and then revised for the next iteration
	works as an example: materials can be stacked in a variety of ways currently missing: opportunities for addition of material are prohibited	• allowing opportune intervention by supplementing blocks with everyday objects
	works as an example: attempting to initiate reflection after each trial currently missing: reflection curtailed by time constraints	• structure and administer reflection to probe for evidence of either single feature consideration or system of features consideration and how that was manifested in the assembly
primary processes of design and processes associated with higher order thinking: analysis of problems, synthesis of resolutions, and evaluation of alternatives (evaluating/improving solutions, collaborative skills) **possible example in NGSS:** **HS-ETS1-2** **Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through**	works as an example: uses interactive/iterative design methodology; explores alternatives; explores scope of constraints (individual features and systems of features); examines existing designs; encourages reflection on process currently missing: exploration of alternatives to problem representation as given – using functional decomposition, exploring graphic representation, redefining constraints, exploring user perspectives	• functional decomposition might involve separating the problem of height from that of resistance to periodic lateral stress, and then combining solutions (or portions of solutions) in order to satisfice both criteria • exploring user perspective involves the manufacture of personas and their relationships with the tower's construction

to increase friction between layers, or whittle notches in the blocks, or otherwise modify them in order to transfer forces throughout a block frame by making connections between block members. If a teacher's aim is to support the development of students' independent critical thought and reflection, contributing to discourse generation and increasing the range of possible solutions, then material that allows the constraints of the problem to be manipulated might be preferred (Mehalik & Schunn, 2006). In that case, any problem statement accompanying the material is not consumed whole, but instead deconstructed by the teacher in order to determine how definitions, such as user needs, were arrived at (Faste, 1987), and any initial constraints become susceptible to revision if there is a way to arrange benefits to otherwise under-represented stakeholders. In other words, the teacher can ask students to consider which initial constraints in the design problem should be reconsidered.

Summary

Again, while we use engineering design as a reference throughout, it must be explicitly understood that our analysis and suggestions are neither comprehensive in a general sense nor exhaustive in any particulars. We expect the teacher to modify or augment the suggestions as needed for the situation and materials at hand.

To retrace our steps, we presented a list of design competencies that are now to be found on teachers' plates, and we conjectured that teachers, especially those without experience in teaching design, would be looking over materials to be used in their classrooms. We then followed with an analysis of a design task (the block tower task) that we ran with students in middle school and high school. That task, as a representative of materials which teachers might encounter when looking for ways to teach design, led us to two main points. The first point is that the teacher should be wary of tasks, such as the block tower task, without prior analysis.

This point arose from our recognition the task did not result in the learning that was expected, although it did lead to some unintended outcomes.

The second and main point is: guidelines for searching materials might be helpful, especially for teachers who are inexperienced in teaching design. We crafted guidelines based on the block tower task and our ideas about how we might have changed it. Our intent is for the guidelines to serve as a starting point for informing teacher choices and modifications. As teachers become more sophisticated in their practice of reactive design pedagogy, further inspection of existing materials in consultation with these guidelines will yield not only many more directions in the implementation of those materials, but also a much wider range of competency related novel materials.

In conclusion, we anticipate two ways to use the guidelines: assessment of material for suitability and likelihood of expansion beyond the original intent of the material. When assessing material for usefulness in design instruction, teachers might consider which concepts or processes are to be emphasized and then review whether or not those can be expected from an implementation of the material. A purposeful application of the guidelines we have provided could lead to discovery of possible the expansion of existing materials and the additional of more affordances the materials can provide.

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