Learning Science by Participating in Design: A Case Where Multiple Design Subgoals Interfere with Systematic Progress

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Research Questions

How do students learn science by participating in team design activities?

When designing in teams, what are the characteristics that distinguish more successful teams from less successful teams?

How do those distinguishing characteristics of the more successful teams lead to better science learning by the students in those teams?

Methods

- Design-based science unit—learning of electricity concepts through engineering design of a system
  - o High level goal is to build an alarm system that includes 3 subsystems: Power, Indicator, & Detector (plus a Control subsystem and fine-tuning).
- 8 teams of 3-4 students selected randomly for study
- Videotaped construction over 4 class periods
- Focused on the 2 extreme teams based on their post-test performance (high and low)
- Compared design activities to look for differences that may explain how the students in one team learned more of the science content than the students in the other

This image is representative of teamwork during the unit. Students in a team worked on a shared springboard building circuits that solved their design tasks and tested their ideas. This group effectively sustained their focus and worked together to test their ideas.

Results

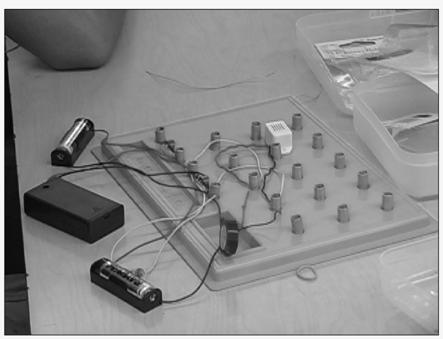
	Team 1 High	Team 2 Low
Mean Post-test Score	0.77	0.50
Mean Circuit Designs Per Day	36	13

The more successful team clearly made many more designs than the less successful teams, but what allowed them to be so productive? Is a simpler, more constrained focus on lower-level design goals more productive than maintaining focus at a higher level?

Design Goals

Design challenges / subgoals when constructing alarm:

- Get an indicator component to work (i.e., a bulb to light or a buzzer to sound)
- Get a indicator component to be louder or brighter
- Get a detector component to work (e.g., have a light detector affect the brightness of the bulb)
- Incorporate an on/off switch that doesn't short circuit the batteries
- Limit what is passed through a component so it doesn't get overheated or so it turns all the way off when the detector is activated



This image is an example circuit built by a student team. The circuit has two buzzers, a bulb, and all four batteries. It also has a short circuit so when the switch is pressed down, the indicators shut off, and the batteries and spring get very hot.

Team 1 — High

S1	Let's turn it the other way then, so the red matches up with red.
S3	Yeah.
S2	No, it doesn't matter.
S1	Well it might!
S3	Yeah. Come on. [Buzzer rings]
S2	Apparently it does.
S1	Loser!
S2	Let's see if we can do both!
S1	Yeah, that'd be annoying.

Team tests a clear idea about matching the color of the wires. Then agree to move onto a new goal.

S4	Hey guys! Leave it on and see if the switch can turn it off.
S1	But that's short circuiting it.
S3	We have to set it up the opposite way, so that we push it down.
S1	Okay, so now we push it there. And now you press again.
S2	And it's getting hot.
S1	Yeah don't. So, how do we make it with the other way? When you push in, it goes off?
S2	I don't actually know.

S1 keeps understanding short circuits as the primary goal and focuses the other students.

S1	If we put this, but we want to push it down to make it go on.
S3	How do we do that?
S1	I think this'll work. Cause look. I need a new battery.
S4	Try using this one. Here, let me see that.
S2	Hold on, I want to try something…
S1	I think this'll work. Push it down. Yeah, see?
S2	Yeah.
S1	Let's put a buzzer. [T]! We made it work.

The team finds a solution to their problem and recognize right away.

S1	We made it, we know how to, like, press it to make it go on. Like you connect one side.
T	And, and when you press it, it turns it on?
All	Yeah.
S1	Like, you connect one side to the battery and the other one.
T	And there was no short?
S1	Right.
S4	And now we're adding more batteries to make it go louder and brighter.

They report their success to the teacher and state that now they are working on a new goal.

S4	Can I try something?
S1	Hang on, I just wanna, like, to make more power, wouldn't more batteries make it?

Refocusing on the new goal.

Team 2 — Low

S6	Okay, now what we need to do is like make the light brighter.
S5	Whoops, uh, you messed up the light [S7].
S6	No, no, I took it our for a reason.
S7	I am trying to put this back in. It fell out.
S6	It didn't fall out. I took it out.
S7 & S5	Why?
S6	Because we have to make this brighter.
S5	Its fine, its fine, its fine.
S5	No its just, that is how the light is.

S6 struggles to get the other two students on the same goal.

S7	I was distracted. What were you saying? Seriously, what were you saying?
S6	I was saying that I think we can make the light brighter.
S5	I think that is just how the light is.
S7	Yeah. We are using double pack batteries. I dunno.Take out the alarm and see if it'll make the effect on the light greater.
S5	Yeah sure. Wait I want to show [T] first.

The students claim the light can't get any brighter and reject the goal that S6 wants.

T	Ok now look, to turn your alarm off though, bud, look, to turn everything off, if I do that, I t's setting up a short.
S5	Oh ok wait, so you don't need to unplug it.
T	You don't want to turn that off like that.
S5	Oh you don't? Why? What will happen?
T	That's a short, see to turn your system off basically you are attaching this to this. Here comes your power it's going across and coming back.That's called a short circuit. See if you can get it where it is off, and when you push the switch it goes on.
S6	[T], I have a question. Could we make the light brighter with the other? [T nods]
S6	See I told you, guys, we can make the light brighter.

Teacher introduces short circuit goal when students have not yet figured the necessary features to make things turn on or to make them brighter or louder. This distracts them.

S7	Well let's try the alarm too, I think with more voltage the same exact alarm will be louder. Hello? Hello?
S6	I don't think the alarm needs to be louder yet.
S7	Yeah, because I remember when we plugged it, when we added the third battery it was slightly louder I think. I'm pretty sure. [S5], did you hear what I said?

[One of their batteries cracks from a short circuit.]

Their batteries crack from a short circuit while they were working on getting the buzzer to be louder.

Conclusions & Implications

We found that the more successful group was able to focus their efforts on one design goal at a time, and move quickly through different designs that built off one another. This efficiency in designing allowed them to test small ideas that, when taken together, enabled them to accumulate pieces of knowledge and construct a coherent understanding of the electricity ideas that carried through to their post-test.

This research is important for our work in helping students to learn science through design as it has implications for designing scaffolds that encourage students to transition from their engineering goals to science goals. Our current work includes testing interventions that encourage teams to focus on one design goal at a time and to identify ideas that enable efficient and effective exploration of the design space and then to understand the electricity concepts.

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Acknowledgements

This research was funded by a grant from the National Science Foundation.