Seventh-Grade Students' Use of Heat Transfer Conceptions During an Engineering Design-Based STEM Integration Curriculum

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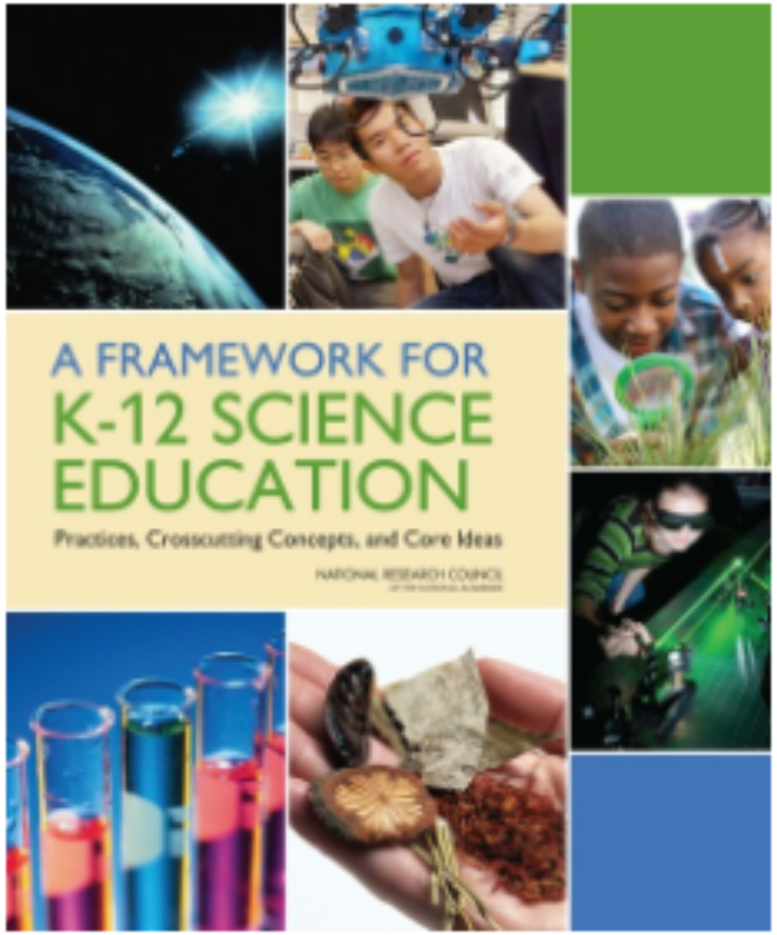
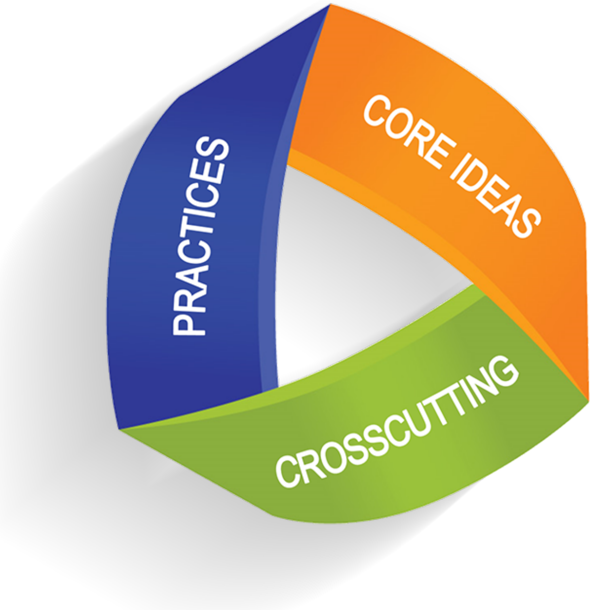
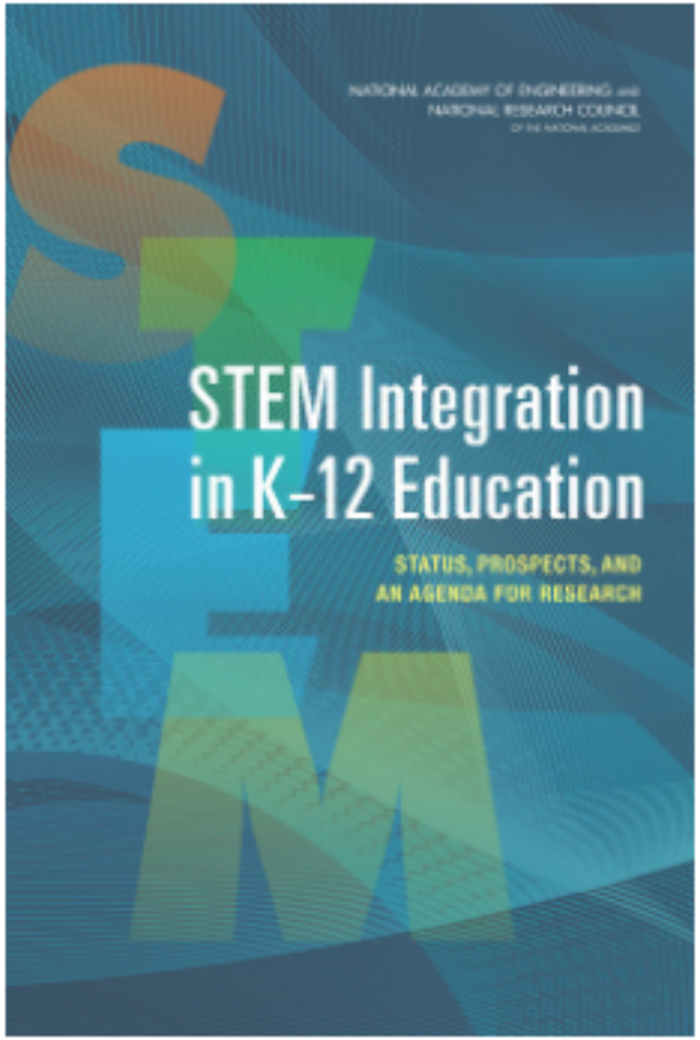


NRC, 2012



NGSS Lead States, 2013



NAE & NRC, 2014

Design-Based Learning/STEM Integration

- In pre-post assessments, students demonstrate significant positive learning gains in science content
  - overall (e.g., Apedoe, Reynolds, Ellefson, & Schunn, 2008; Fortus et al., 2004)
  - when compared to control classrooms (e.g., Kolodner et al., 2003; Mehalik, Doppelt, & Schunn, 2008; Schnittka & Bell, 2011)

- In students' talk and writing during design-based activities, they have shown mixed results in terms of
  - how much unit-based science they apply (e.g., Guzey & Aranda, 2017)
  - how well they apply science concepts to design (e.g., Mathis et al., 2018; Schnittka & Bell, 2011)

Heat Transfer Conceptions

- There are many alternative conceptions about heat transfer across all age groups (e.g., Clough & Driver, 1985; Lewis & Linn, 1994; Wong, Chu, & Yap, 2016)
  - Metals "attract" heat and cold (e.g., Clough & Driver, 1985; Lewis & Linn, 1994; Schnittka & Bell, 2011)
  - Heat rises or moves (e.g., Clough & Driver, 1985; Schnittka & Bell, 2011; Wong et al., 2016)
  - Using the sense of touch to determine temperature vs. rate of heat transfer (e.g., Clough & Driver, 1985; Lewis & Linn, 1994; Schnittka & Bell, 2011)

- Conceptions about specific processes of heat transfer (i.e., conduction, convection, radiation) are less well documented

Research Question

During an engineering design-based STEM integration unit, what scientific and alternative conceptions about heat transfer does a team of middle school students use?

Single Case Study Design (e.g., Yin, 2018)

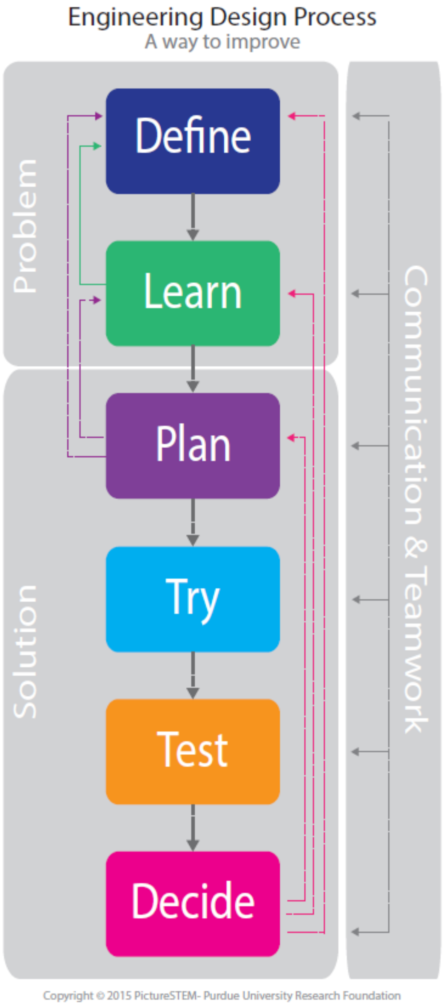
- **Setting:** Jr/Sr High school in rural Midwest
- **Context:** Engineering design-based STEM integration unit implemented by a science teacher (Mr. Parker)

- **Case:** One team of 7th grade students

Case: Student Team

- Dylan
- Marie
- Noelle
- Sheldon

Ecuadorian Fishermen: An EngrTEAMS Unit



1: Defining the Engineering Problem
2: Temperature and Heat Transfer & Convection
3: Heat Transfer Through Conduction
4: Heat Transfer Through Radiation
5: Analyzing the Absorption Properties of Materials
6: Getting to Know the Context
7: Exploring Materials and Planning: Idea Generation
8: Planning: Idea Selection and EBR
9: Trying/Building the First Prototype
10: Testing and Deciding About the First Prototype
11: Redesigning a Second Prototype
12: Communicating with the Client

Data Collection

- 21 class periods of data
- Video and audio of student team and whole class, student team artifacts (engineering notebooks and prototypes), field notes
- Minimal researcher involvement

Data Analysis

- Procedures from qualitative content analysis (Schreier, 2012)
- Deductive and inductive coding categories
- Construct validity – triangulating multiple sources of evidence
- Reliability – peer checking

Heat and Temperature

- Implicitly distinguished between ”temperature” and “heat”
  - Not always true of middle school students (Schnittka & Bell, 2017)
- Mostly used “heat” as a process of thermal energy transfer: “to heat up,” “heat transfers,” “absorb heat,” “conduct heat”
- Only twice used the term “thermal energy,” even after it was introduced as a key vocabulary term
  - Experts often use “heat” in cases where “thermal energy” would be more appropriate (e.g., “heat transfer” instead of “thermal energy transfer”) (e.g., Bauman, 1992)

More about Heat Transfer

- Almost always correctly said “hot air rises” or “hot water rises”
  - Contrast: a common alternative conception is that “heat [is a substance] that moves” (Clough & Driver, 1985; Wong et al., 2016)

- Consistently used the scientific conceptions that the direction of heat transfer is from hotter objects (i.e., objects with higher temperatures) to colder objects (i.e., objects with lower temperatures)
- Also always used “cold” as an adjective
  - Contrast: a common alternative conception is that cold is a substance, the opposite of heat, that moves (Clough & Driver, 1985; Wong et al., 2016)

Feeling Temperature vs. Rate of Heat Transfer

Materials at the same temperature can feel different because they transfer heat at different rates

Created a heuristic →

A material that feels colder (at ambient temperature) will transfer heat faster

- Similar findings to another heat transfer-focused, design-based curriculum implementation that also targeted the common alternative conception about how materials feel (Schnittka & Bell, 2011)

Conduction Lesson

Context: The student team was given a brass block and a rosewood block. They needed to predict which would melt ice faster if an ice cube was placed on each of the blocks.

Mr. Parker: Make sure you've discussed with your group and talked about why you believe one is going to melt the ice faster than the other.

Sheldon: I'm gonna say brass-

Noelle: So I say brass because-

Sheldon: -cause, **cause it's gonna bring the heat out faster**.

Noelle: Yeah, like, **heat travels better in that [brass block]**, I would say.

Scientific conception: Heat transfers more quickly through metals (conductors) than though plastic, paper, or wood (insulators)

Exploring Materials

Context: The team needed to predict which of their available materials would be better conductors.

Marie: Wait, this one [white felt] would be a great, for number 1 because it had 69 from the test *(looks at radiation lab data table).* Right?

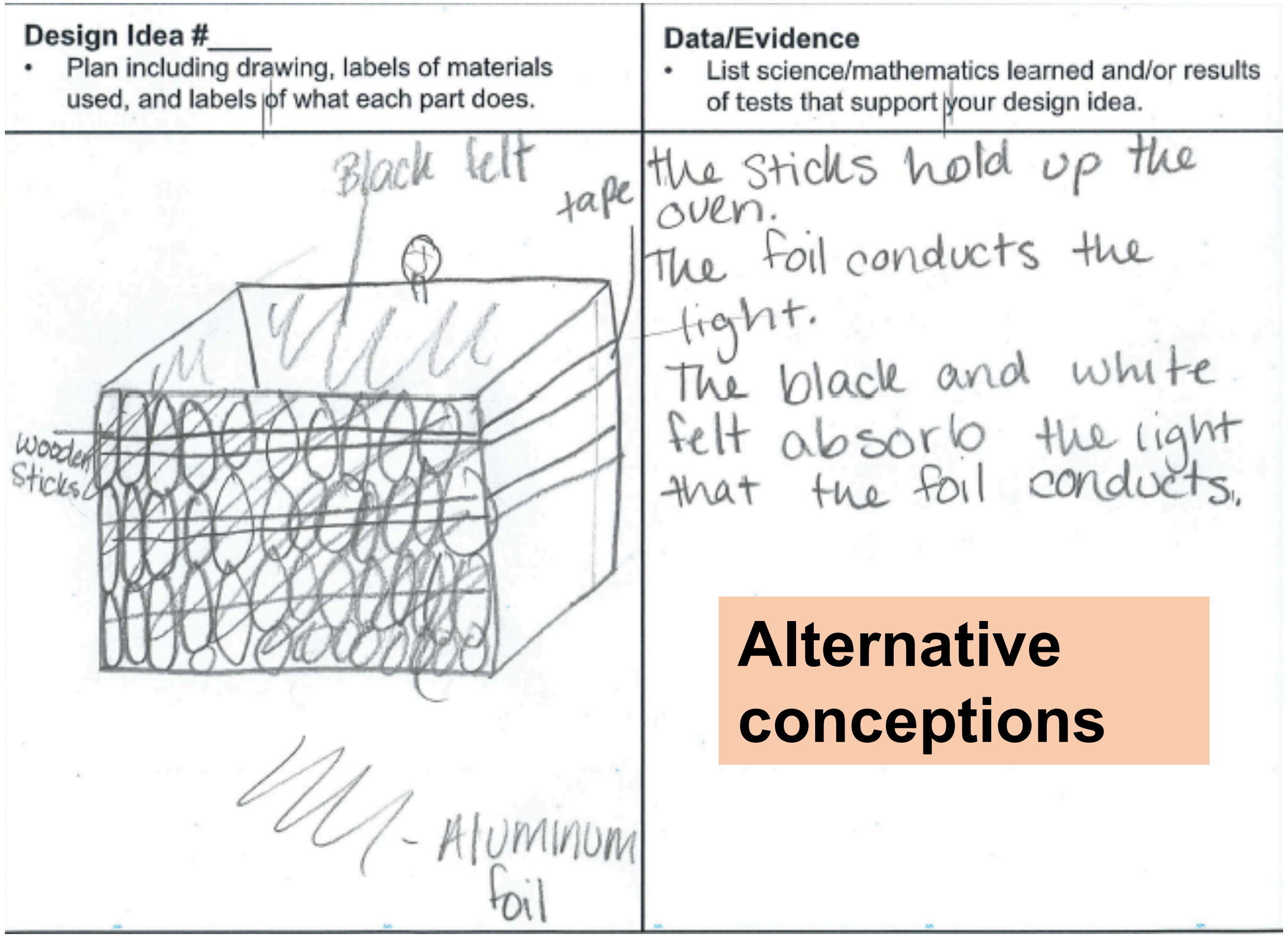
Noelle: Okay, um, *(re-reads the question prompt)*, "Question 1: Which materials will best transfer heat via conductor?"

Marie: The white felt

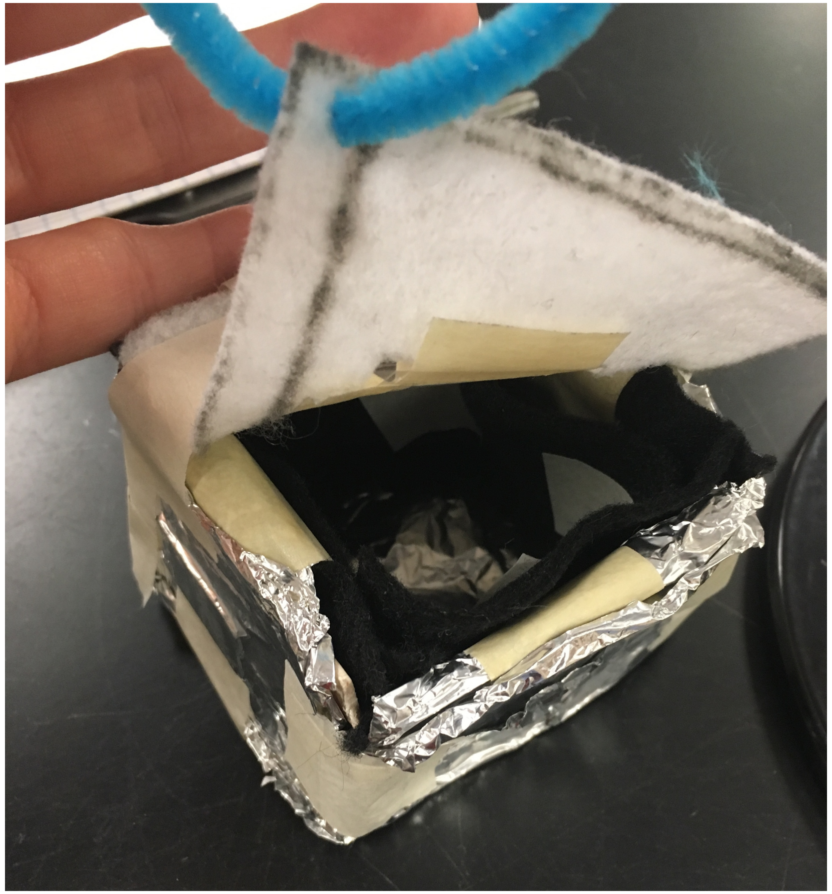
Noelle: The white felt because it had the highest, it has the highest temperature.

Alternative conception: White felt is a good conductor because it had the highest temperature increase (during the radiation lab).

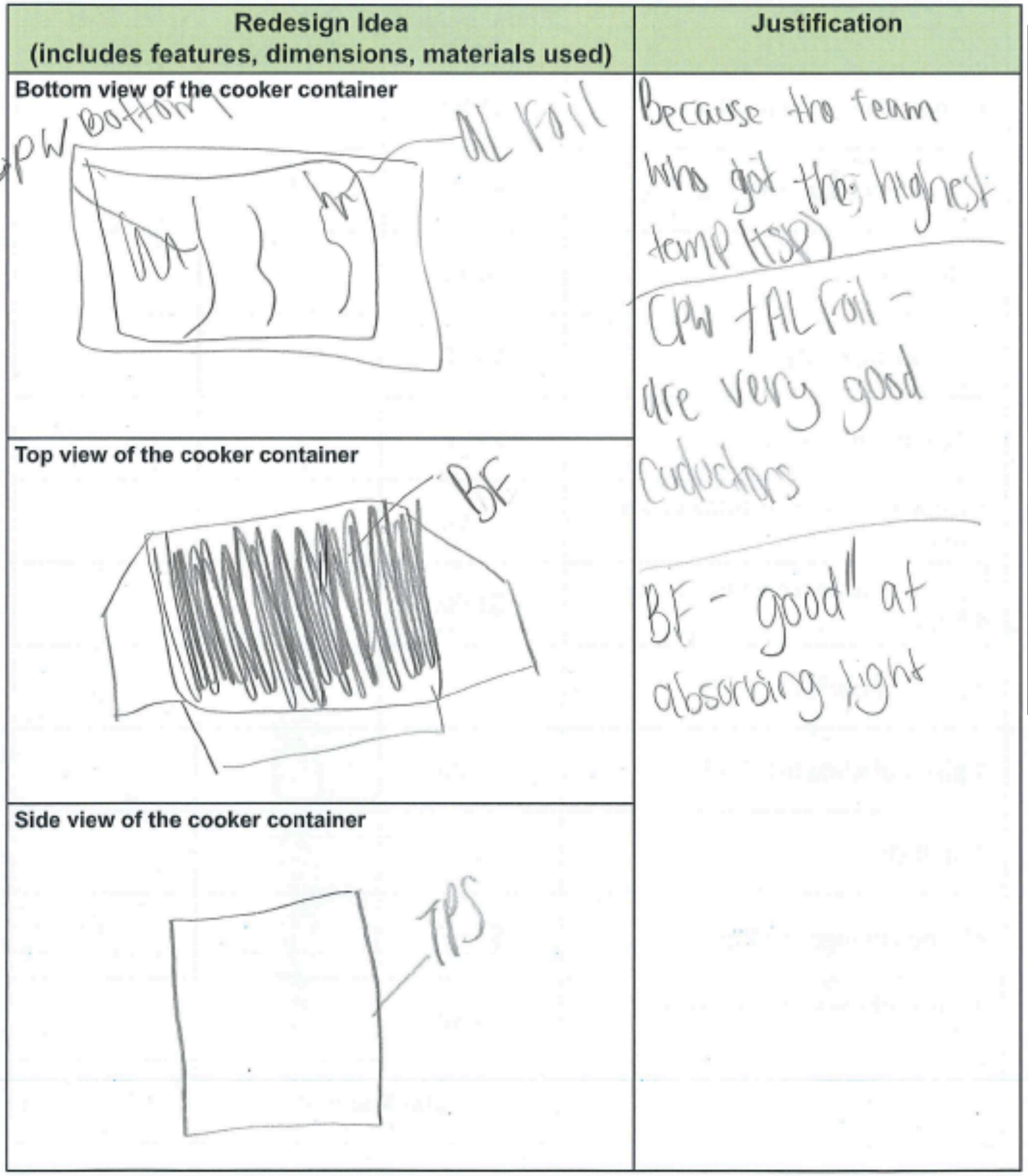
Initial Design Plan and Prototype


Design Idea #____ • Plan including drawing, labels of materials used, and labels of what each part does.	Data/Evidence • List science/mathematics learned and/or results of tests that support your design idea.
Black felt tape wooden Sticks Aluminum foil	the Sticks hold up the oven. The foil conducts the light. The black and white felt absorb the light that the foil conducts.

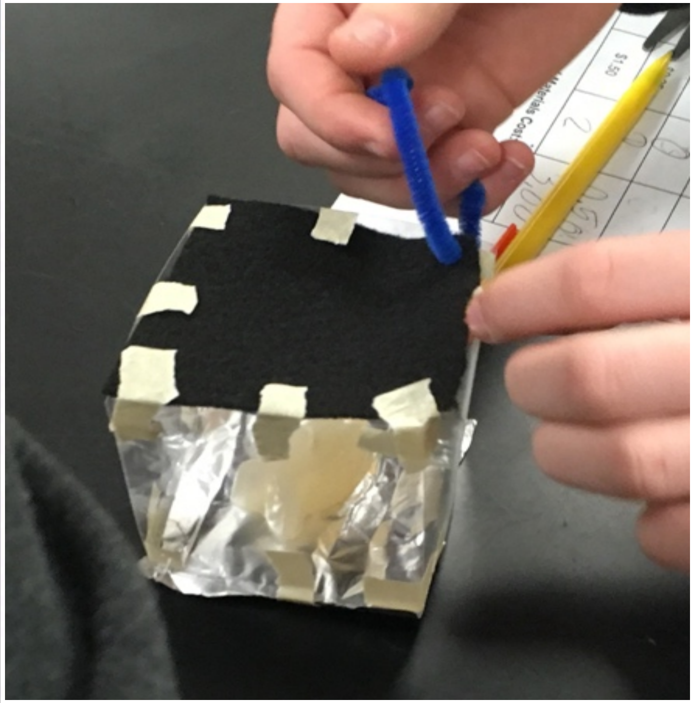
Alternative conceptions



Redesign Plan and Prototype



Redesign Idea (includes features, dimensions, materials used)	Justification
Bottom view of the cooker container CPW bottom AL foil	Because the team who got the highest temp (TSP) CPW + AL foil - are very good cuductors BF - good at absorbing light
Top view of the cooker container BF	
Side view of the cooker container TPS	



Scientific conception*: The cooker container with transparency sheet top and sides had the largest temperature increase during prototype testing

Scientific conceptions:

- Heat transfers more quickly through metals (conductors) than through plastic, paper, or wood (insulators)
- Dark colors absorb radiation/light energy

Summary of Findings

- Many typical heat transfer alternative conceptions were scientific conceptions for student team
  - Heat vs. temperature
  - Scientifically acceptable ”heat” phrases
  - Objects at thermal equilibrium can feel different based on rate of heat transfer

- New alternative conceptions not in literature were present
  - Confusion about conduction and radiation

- Confusion consistent with other literature about heat transfer (Clough & Driver, 1985; Lewis & Linn, 1994)

Contribution to Teaching and Learning Science

- Continued exploration of the effectiveness of engineering design-based STEM integration
  - In this model, students learned and consistently used some scientific concepts about heat transfer

- Revealed new alternative conceptions about conduction and radiation
  - Students distinguished between heat transfer processes during science-focused lessons
  - Alternative conceptions exposed when they attempted to combine and apply the concepts to solving and engineering challenge

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