Impact of Choice on Students' Use of an Experimentation Model for Investigating Ideas about Thermodynamics

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Abstract: This paper examines the impact of providing choice on students' use of an experimentation model to investigate their ideas using an online thermodynamics unit. Sixth-grade students working in pairs (N = 78) were randomly assigned to either a *choice* or *no-choice* condition for investigating the insulation effectiveness of different materials. The choice students were asked to select one of two equivalent scenarios to investigate with the experimentation model. In contrast, the no-choice students were randomly assigned a scenario to investigate. Our findings indicate that the choice students more often used the model to test their prior ideas than their no-choice peers. Furthermore, the choice students also ran more informative experimentation test patterns that yielded valid and useful data for understanding heat energy transfer with the model. The findings from this study provide promising insights into the potentially beneficial impact of incorporating choice into science learners' experiences in the classroom.

Rationale and research objectives

This study investigates how providing choice during instruction impacts students' use of an interactive experimentation model in *Thermodynamics Challenge*, an online curriculum unit about heat energy transfer and thermal equilibrium. Providing different investigation choices can make the learning experience feel more personally relevant for students (Cordova & Lepper, 1996), which can in turn lead to more effortful self-regulated and metacognitive learning (Kamii, 1991; Pintrich, 1999). Although choice has been examined across a variety of educational contexts ranging from school choice (e.g., McLaughlin, 2005) to example choice (Reber, Hetland, Chen, Norman, & Kobbeltvedt, 2009), studies investigating the impact of choice in authentic classroom settings for a complex learning task such as scientific inquiry are rare (refer to: Flowerday & Schraw, 2000; Reber, Hetland, Chen, Norman, & Kobbeltvedt, 2009). We take the view that the sense of competency, relevancy and autonomy that providing choice can impart to students (Katz & Assor, 2007) may positively impact how they engage with learning. This study builds on prior research investigating the impact of choice on student learning outcomes within an authentic classroom context (King Chen, 2016), and we hope it provides additional insight into the potential value of providing choice during science inquiry instruction.

Theoretical and methodological perspectives

This research work views learning from a constructivist perspective—that learners' pre-existing ideas can be effectively leveraged towards more normative and integrated understandings of challenging science ideas and concepts (Smith, diSessa, & Roschelle, 1993). The *Thermodynamics Challenge* curriculum unit was designed using the *scaffolded knowledge integration framework for instruction* (Linn, Davis, & Eylon, 2004), which specifies four iterative processes that can help students to integrate new ideas with their existing understandings as they engage in inquiry: elicit prior ideas, introduce normative scientific ideas, help establish criteria for evaluating ideas, and encourage the sorting and refinement of one's repertoire of ideas.

As a design-based research (DBR) study, this work aims to inform and advance the development of theories of learning as well as the design of innovative learning environments (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). The primary hallmarks of DBR are iterative cycles of implementation and evidence-supported refinement (e.g., Collins, Joseph, & Bielaczyc, 2004; Sandoval, 2014).

Methods and study design

Thermodynamics Challenge curriculum unit and experimentation model

Thermodynamics Challenge (or *Thermo* Challenge) was developed using the Web-based Inquiry Science Environment (WISE; Bell, Davis, & Hsi, 1995). The unit encourages students to apply their ideas about thermodynamics (specifically insulation, conduction, heat energy transfer and thermal equilibrium) towards the testing and evaluation of different materials for insulating a beverage using an experimentation model. We designed the model to function as an interactive space for testing ideas, running experiments and making sense of acquired data. Students modify two parameter settings (cup material and starting liquid temperature) before running the model to observe the transfer of heat energy over time and the resulting heating or cooling temperature curve.

Iterative refinement of the model and user interface

During our previous classroom implementations of the *Thermo Challenge* curriculum unit, we observed many students adopting a perfunctory approach towards using the model (e.g., completing a random subset of tests in a haphazard manner, or running quickly through all the test possibilities to "complete" the work) rather than taking a more self-directed and reflective approach towards conducting their experiments (i.e., making intentional decisions about which experimental tests to run and why these tests might be useful for improving their understanding).

Based on these observations, we redesigned the model interface to more explicitly promote students in engaging in reflective and self-directed experimentation with the model. Specifically, we made design changes to better support students with the following key scientific practices (NGSS Lead States, 2013): planning and carrying out an investigation, using the model to investigate ideas and explanations, and analyzing and interpreting data obtained from the model. The new design feature that supports students with these activities is the *experimentation matrix*, which allows students to easily view the full range of experimental trials for their planning, investigating and analyzing activities with the model (see Figure 1). (The matrix replaced the drop-down parameter menus previously available for operating and interacting with the model.) As can be seen in the figure, the column headers of the matrix indicate the six different materials available for testing (i.e., aluminum, wood, styrofoam, plastic, clay and glass) and the row headers of the matrix show the three starting liquid temperature options (i.e., hot, warm and cold). The resulting 3 x 6 matrix thus allows students to track the 18 possible experiments that they can run with the model. The experimentation matrix and supporting curriculum scaffolds aim to engage students in more directed and deliberate experimentation with the model: Students first use the matrix to discuss and record the key tests they want to run (*planning*; the matrix logs students' preferred tests as "starred" experiments), they then use the matrix to select tests to run with the model (*experimentation and data collection*) and finally, students use the matrix to choose a subset of their collected data for scaffolded analysis and sense-making (*interpretation*).

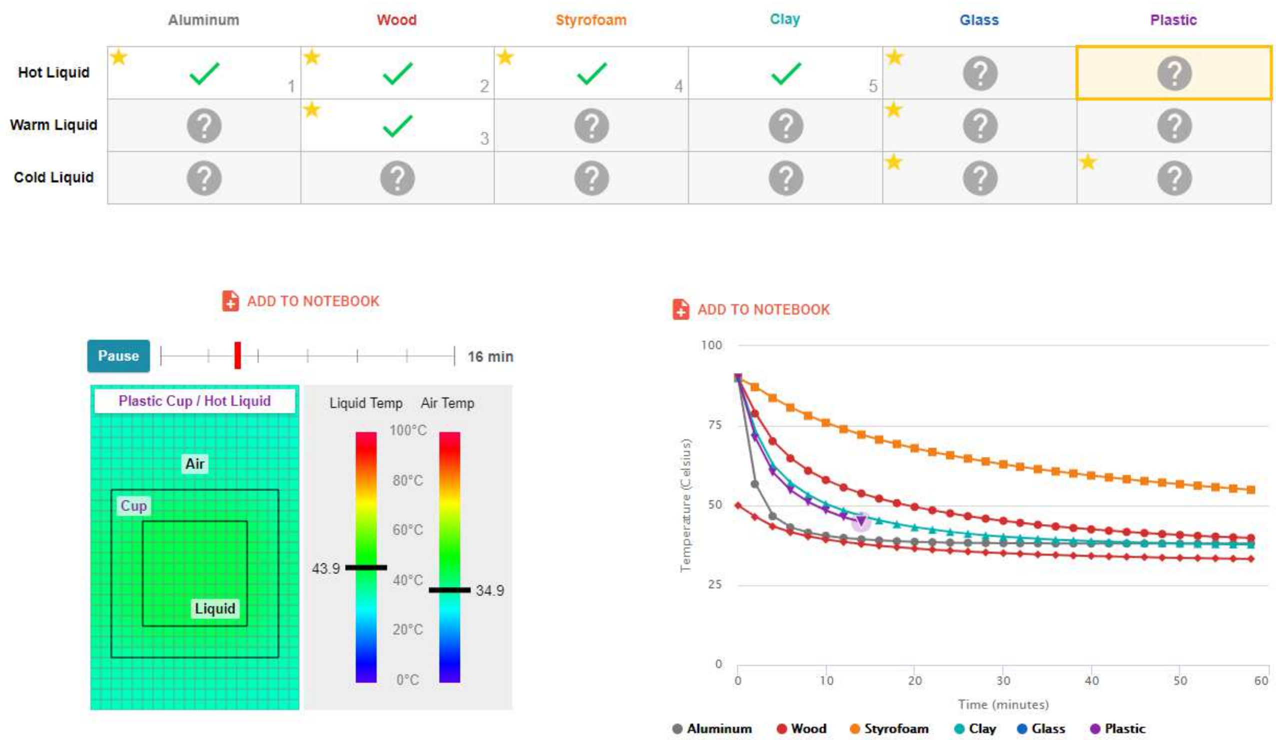

Figure 1. Screenshot of the experimentation matrix and interactive model in *Thermo Challenge*. Students use the matrix to plan their key trials for investigation beforehand (recorded in the matrix as "starred" tests). Students then use the matrix to run the model (completed tests are indicated with green check marks).

Choice study design and data collection

As stated previously, this study investigated the effect of providing choice on students' use of the *Thermo Challenge* model for investigating their ideas about thermodynamics. 156 sixth-grade students taught by one teacher at a public middle school participated in the study. Student pairs were randomly assigned within class periods to either the *choice* (N = 38) or *no-choice* condition (N = 40) and completed the unit over four hours of classroom time. Students in both conditions received exactly the same instructional content with only one difference: The choice students were offered the choice of two equivalent scenarios to investigate with the model (how best to insulate either a hot or cold beverage over time). In contrast, the no-choice students were randomly assigned to investigate either the hot or cold beverage scenario.

We captured the following sources of data: students' individual responses to the unit pre- and post-test, student pairs' written responses to embedded assessment prompts in the unit, their experimentation decisions with the model as logged by their use of the experimentation matrix, our classroom observation notes, and recorded video data of student pairs working together.

Results and discussion

For the following analyses we examined the data logged by students' use of the experimentation matrix, specifically: Which experimental tests students *flagged beforehand* as important for their investigations, and which tests they *actually completed* and collected data for with the model. We present two primary findings.

Fidelity of implementation of planned experimental tests. We hypothesized that the choice students might demonstrate a higher fidelity of implementation (i.e., completing and collecting data for more of their planned tests). Our reasoning for this hypothesis was that the choice students might feel more engagement or ownership (and consequently, a greater sense of commitment) for carrying out their chosen investigation with the model compared to their no-choice peers (who were assigned to investigate either the hot or cold beverage scenario). Our analysis for fidelity of implementation found evidence to support this hypothesis. Students in the choice condition demonstrated a higher rate of following through and carrying out the experimental tests that they flagged during the experiment planning step compared to the no-choice students. This result was found to be statistically significant using the Chi-square test ($p < 0.05$). In other words, the choice students more often used the model to test their prior ideas (the experimental tests they starred as the important ones for adding to their understanding of thermodynamics and their selected scenario during experimentation planning). We interpret this finding as an indication that giving students choice may provide them with the opportunity to engage in more self-directed learning; in this case, following through with the investigation of a scenario that students were able to choose for themselves. Since both choices are equivalent scenarios (the physics behind heat energy transfer for a hot or cold beverage are exactly the same), we posit that the effect of choice seen here is more likely to be an affective or motivational one. Furthermore, as offering choice allows the option to choose a more personally relevant situation to investigate, learners might have used the opportunity to examine and possibly build on their prior ideas about various materials using the model (e.g., "a steel water bottle keeps my water cold, so steel must be a good insulator").

Frequency of informative experimentation patterns. Another interesting finding from this study emerged when we analyzed the patterns of experimental tests students ran with the model. In our analysis, we looked specifically for completed sets of tests that demonstrated evidence of experimental proficiency or systematicity that would yield informative data for students to draw scientifically valid conclusions from their use of the model. (Some examples include: Running a set of tests that compared materials by controlling for starting liquid temperature, or running matched temperature tests for the same set of materials.) Again we found that the choice students demonstrated a higher rate of informative experimentation patterns than their no-choice peers. Interestingly, this finding was not found to be significant using the Chi-square test for the cold beverage students (comparing choice to no-choice) but was found to approach significance for the hot beverage students (choice versus no-choice; $p = 0.07$). This finding raises a potentially interesting avenue for further analysis and investigation. For the entire population of choice pairs, 61% chose to investigate the cold beverage scenario, and only 39% chose the hot beverage scenario. These percentages suggest that students might have a preference for (or more familiarity with) thinking about the cold beverage scenario. Our previous observations and studies examining students' ideas about thermodynamics would seem to support this hypothesis. We have noticed that most students generate responses about heat energy transfer by referring to everyday experiences about keeping a beverage cold (refer to the steel water bottle example given above) rather than keeping a beverage hot. Another piece of evidence that lends weight to this idea from our analysis of the logged matrix data is that testing a cold liquid in an aluminum container was by far the experimental test students *most frequently selected whether during planning or data collection with the model*. Taken collectively, we hypothesize that these findings might provide evidence for the instructional value of utilizing choice as an instructional approach that provides students with the important opportunity to engage in the learning of new ideas through activation of their prior knowledge and understandings. We acknowledge that this is at present a speculative conclusion that requires further investigation and evidence. (Additional analyses of the other data sources collected from the study are currently underway to find more evidence in support of this hypothesis.)

Instructional value of student choice and the experimentation matrix for collaborative learning. Another possible explanation for the promising findings we have found in favor of choice might be that requiring student pairs to choose an investigative topic promotes the need for collaborative discussion with a partner in order to negotiate ideas and preferences to reach a consensus about which investigative scenario to choose. In other words, choice promotes discussion and the need to collaborate during learning. Furthermore, the activities with the experimentation matrix are designed such that student pairs must negotiate decisions together (e.g., which experimental tests to star during planning; which tests to run with the model). Thus the matrix can help to make student thinking visible and available for discussion by providing an accessible, shared learning space for continual discussion, the negotiation of experimentation decisions, and sense-making.

Conclusions and implications

We propose that the findings from this study, although preliminary, provide promising insight into the beneficial impact of incorporating choice into learners' experiences in the classroom. It is worth noting that we observed these positive impacts using a relatively simple embedding of choice in the curriculum, and that the study was implemented over only four hours total of instruction. We anticipate that other choice design studies employed over longer spans of instruction may yield even more positive and powerful benefits for learners. We hope that this work will help to serve as a starting point for more conversations with other researchers in the learning sciences community about how to design instructional innovations and technological tools that can support students' engagement with learning through choice and collaborative sense-making of complex scientific ideas.

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