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Students know more than they can tell: Understanding learners' ideas of heat transfer via model revision activities

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Abstract: Students' preconceptions significantly influence learning as they bring prior experiences and ideas alongside formal knowledge. Considering only explicit or conscious conceptual models can misinform teachers' efforts. Framing the problem using both conscious (verbal-symbolic knowledge, conscious models) and unconscious (implicit models, core-intuitions) conceptual resources offer a powerful framework. This study interprets the ideas of heat transfer of two grade 11 students in depth (from a total N=9), through this framework. We look at how Nash and Payal use different conceptual resources to build an explanatory model of heat transfer in a cup through the model revision activities. We found different ideas of heat (heat as a substance, steam as unique property of heat) to be unconsciously influencing how students understand the concept. Harnessing core-intuitions into conscious models enabled Nash to build better explanatory models, whereas Payal extensively relied on her verbal-symbolic knowledge. In the macroscopic activities, both students tended to use their judgments from their sensory perceptions, going against their verbal-symbolic knowledge. Using the metacognitive prompts on Knowledge Forum also supported student's critical analysis about their ideas before uploading them on the forum.

Keywords: Conscious models, unconscious models, intuitive knowledge, representational levels, perceptions, Knowledge Forum, explanatory models

1. Introduction

Students' preconceptions have a serious impact on their learning of new material. They bring with them their experiences and ideas of the world while also consciously reasoning about concepts taught as formal knowledge (Piaget, 2013). Hence, considering student responses to draw only from their verbal explanations or simply identifying non-normative notions to be the result of incorrect interpretation of instruction may misinform an instructor's efforts in harnessing students' 'own' ideas (Taber,2010). Looking at the problem through the models of knowledge classified as explicit/conscious (decisions we consciously and deliberately take) and implicit/unconscious (decisions taken intuitively, mostly drawn from our mechanistic interaction with the world) can be a powerful framework to achieve this (Brock, 2015; Taber,2014). There is much evidence of learning difficulties in science education because of the ready activation of different implicit knowledge elements, overpowering the need for canonical or sophistication explanation (Brown and Hammer 2008; Taber and Garcia-Franco, 2010). Students use of conscious and unconscious conceptual resources have been reported previously. Students express ideas where unstated implicit models and intuitions may underly their conscious models (diSessa,1988; Vosniadou and Brewer, 1992; Watts & Taber, 1996). Conscious conceptual resources include the formal knowledge that students state using verbal-symbolic knowledge or use conscious models like gesturing or representing unseen elements in diagrams. Unconscious conceptual resources include core-intuitions about domain-general ideas about how things work or the implicit models like domain-specific tacit assumptions (Brown, 1993). Students created sophisticated explanatory models of magnetism when involved in unconscious ways of thinking (implicit models and core intuitions) (Brown & Cheng, 2010). Different instances such as use of verbal-symbolic knowledge abstractly, connecting verbal-symbolic knowledge only to implicit models, over reliance on implicit models, incorrect use of core intuition or anthropomorphic models improperly impeded students' explanatory model building processes (Brown, 2017). Implicit knowledge elements in chemical contexts ("materials naturally react") were more about the fundamental nature of the world (Taber,2010) and less about the intuitive sense of the mechanism as reported by diSessa's in the context of physics(diSessa,1993).

Despite knowing the value of looking at students' conceptions through the implicit knowledge elements views, there is dearth of such research in science education. There are still many unanswered questions such as - do students' intuitions align with normative models of science, what activates the use of certain intuitions over symbolic knowledge, etc. (Brock, 2015). We situate the current paper's work across the multiple levels of representation to uncover students' understanding of a transport phenomenon, heat transfer. We use Knowledge Forum (KF) to help us support and elicit students' scientific knowledge building process (Lin & Chan,2018). This paper focuses on addressing a few of the reported gaps through the research question : How do novice students build and refine their explanatory models of a scientific phenomenon on Knowledge Forum using explicit and implicit cognitive resources?

2. Methodology

Students who had completed the topic of thermal properties of matter and, heat transfer were considered for this study using a purposive sampling. A total of nine grade 11 science students, from schools in the closest cities were part of the study. The schools follow the SSC and ICSE curriculum. For the purpose of this study, we have reported the analysis of two students whose data was pertinent to our research. The study was conducted in, a studio-style collaborative classroom at IIT Bombay, India. Each group had access to a laptop, materials, and papers. Students' discourse in the group were captured using a voice recorder, camcorder, and a screen recorder. Students' interactions in the simulation platform, Knowledge Forum was captured by recording the screen in the laptop. Explanatory models on the Knowledge Forum and the paper sketches were used for artifact evaluation.

To elicit students' reasoning, we used an explanatory model-based approach, where students could organically discuss and bring out their individual ideas as they worked together. The study was designed around the multiple representational levels of chemistry- the macroscopic level (experimentation with cups), microscopic level (simulation and molecular explanation) and symbolic level (explanatory models). The groups were asked to create an explanatory model on Knowledge Forum (KF), to explain the heat transfer phenomenon in a coffee cup. Before the activity began, the researchers demonstrated the different prompts and features of Knowledge Forum, and how to go about using them. The default prompts in the KF were used throughout the activities as it is as they were suitable to address our study. We particularly did not direct students to use the scaffolds and they had the autonomy to use them. The explanatory models were revised on the Forum by the groups after each activity. A total duration of approximately 3.5 hours was utilized in the execution of the activities. The description of the activities is detailed in Table 1.

Table 1. Summary of Activities

Activities	Description
Pre-Knowledge	Researcher conducts active recall about concepts of heat, temperature, and examples
Observe and discuss (single cup)	Researcher pours hot water and adds coffee powder. Each group is asked to observe the cup and discuss their ideas of the cup is cooling down.
Explanatory model on KF	Groups create an explanatory model to explain the heat transfer in a coffee cup on KF
Observe, discuss, choose (multiple cups)	Groups are given different cups, aluminum foil, milk, coffee, hot water to play around and choose the cup which will cool down the fastest.
Explanatory model on KF	Groups update their model on KF with new insights or observations

Molecular simulation and representation of cup	Groups are asked to create(draw/describe) a molecular representation of the chosen cup. The groups are asked to interact with the molecular workbench simulation on heat and temperature during the activity.
Explanatory model on KF	Groups are asked to update the molecular representation in the model on KF
Expertise level	Groups are asked to divide themselves each into one type of heat transfer (conduction, convection, and radiation). Each expert group is given a mix of examples of conduction, convection and radiation and asked to choose three examples of their respective expert group and justify their choice)
Explanatory model on KF	Groups create an expertise model on KF
Final Discussion	All members return to their home groups and discuss their findings
Explanatory model (updating)	Final updating of models, if any by the groups

We found the framework by Brown (1993) to be best suited to analyze our students' conceptions. The elements of the framework consist of verbal-symbolic knowledge, conscious models, implicit models, and core intuitions. Verbal-symbolic knowledge: consciously remembered verbal principles, generalizations, or equations, conscious models: conscious imaging like gestures, drawings, verbal, or written descriptions, etc. to explain different causal entities, Implicit models: tacit assumptions about a phenomenon, core intuitions : unconscious model where students use gut-level intuitions about causal interactions of different entities. Using these categories of conceptual resources, we attempt to construct an understanding of student's ideas about the heat transfer phenomenon. Using a comparative-cross analysis method, we looked at two cases of students from two different groups to understand the ways different knowledge elements are used. During the initial screening of the data, we found these two students to be using contrasting reasoning while explaining the heat transfer process where Nash was attempting to integrate different ideas (his own and from experimenting), and Payal resorted to formally taught ideas often. We thought it to be useful to further investigate these two cases in detail. We employed a generative interpretation method based on the verbal and non-verbal discourse by students, the diagrams, the explanatory models on the Knowledge Forum platform and the sketches and explanation on the paper (Clement,2000).

3. Findings

Ideas about heat- Heat as a substance: Nash's explanations during his observations with the cup helped us uncover his implicit views about heat. For example, *"When we touch it, we actually take some heat energy to us"* tells us about how Nash might unconsciously be considering heat as a substance. The properties of substances such transitional, locational, containable, etc. became implicitly applicable while reasoning about the phenomenon. We also observed Nash's overreliance of an observed behavior of heat transfer, steam. Nash uses conscious models gesturing the way heat *moves* from cup to the table. Steam was seen as a source or container of heat. In his statement, "*Vapor will be transferred, and the table will absorb the heat energy*," we see how heat is considered to be contained in the vapor, confirming how heat is viewed as a substance. Payal also demonstrates this view of heat in some instances like "*when we give it heat, it becomes hot, only then it will conduct right?*" where she considers heat as a substance *given*. Even in another instance where she mentions "*hot molecules of water coming from the shower*," hot molecules are considered as substances.

Ideas about heat- A phenomenon should have something unique: Unlike Nash, Payal had another view of heat should have something 'unique'. In her statement, *"There should be something unique about heat, right? We can sense heat, yeah! ,"* she identified 'steam' as a unique property of heat. She used it to reason across the macroscopic level activities while choosing if something is hot/cold. When she had to choose the cup that cooled down the fastest, Payal relied on her reasons generated by touching the cup and 'sensing' the heat of the cup. This idea about heat could also have supported Payal's reasoning with sensory perceptions.

Ideas about heat- Agentic views: Students unconsciously assign different sorts of agencies to the actors in the given situation. These attribute clusters operate at a deep, unconscious level of core intuition, and are not articulated in the verbal language. In Nash's statement, "*when we touch it, we actually take some heat energy to us*," the person is the initiating agent, and the touching initiates an agentic behavior that '*takes*' the heat from the cup (affected responder, heat taken from the cup by the initiating agent (see Figure 1). In the conversation [*Nash: The part of the table in contact with the cup, absorbs the heat from the cup*, *Riya: (The cup) it transfers the heat*, *Nash: "Absorb or transfer? Absorb. Transfer means it gives."*] even when his teammate suggests 'transfer' in place of 'absorb,' Nash insists on using 'absorb' and adds that transfer means '*it gives*' to indicate the initiating agent as the table, as opposed to the cup.

Sensory perception over Formal knowledge: During the macroscopic level activities, Nash extensively used his actions of '*feel*' and '*sense*' to reason or make judgments. He investigated perceptually (by holding, touching and watching the materials) as well as scientifically (by systematically measuring temperatures of different coffee cups using thermometer). Even though he recalled and stated his verbal-symbolic knowledge about metal being a good conductor of heat, experimental measurements of the cups along with perceptual 'feel' gathered by interacting with the materials including the cup, dominated his judgment. Payal also encountered multiple instances where her formal knowledge about metals being a good conductor of heat was questioned because of her perceptual observations where she decided the degree of hotness of the cups by *sensing* them. Another reason why the perceptual views of both students overpowered their formal knowledge could be because of their implicit views about how conduction works. They may be considering the metal cup to be hot because it is '*holding*' the heat, hence no heat transfer. While they were correct in observing it, their implicit ideas about heat impeded their inferences.

Integration of conscious and unconscious knowledge: The most noticeable difference in Nash's and Payal's ways of scientific reasoning was the use of the different conceptual resources. Nash, who had a sophisticated explanatory model, largely used his intuitive knowledge, perceptual observations, and meta-conceptual awareness . He rarely relied on his verbal-symbolic knowledge, using it only to support or anchor his reasoning. We could also see him invoke conscious models to explain the mechanism of the phenomena like movement of steam or energy from the cup to the surroundings. Unlike Nash who relied on his verbal-symbolic knowledge occasionally as a support, Payal constantly relied on her verbal-symbolic knowledge not as a support but as a main means to build the explanatory model. We could rarely see her draw on her intuitive knowledge. We also see a lack of meta-conceptual awareness in Payal's model iteration process.

A framework of Nash's ideas of heat transfer: Nash's use of multiple conceptual resources can help us understand how the resources interacted to build his understanding of heat transfer. Using his most dominant view of heat, we drew a representation to explain the interplay of all the resources at the macroscopic level activity as depicted in Figure 1. The verbal symbolic knowledge helped him create two different conscious explanatory models of heat transfer. These conscious models were implicitly dictated by his views about heat being an object(substance). Core intuitive resources such as attribute clusters underlined the explanation of how Nash saw hand causing heat transfer. This representational diagram helps us "see" briefly the way different conscious and unconscious conceptual resources could work towards building an understanding of a phenomena for a student.

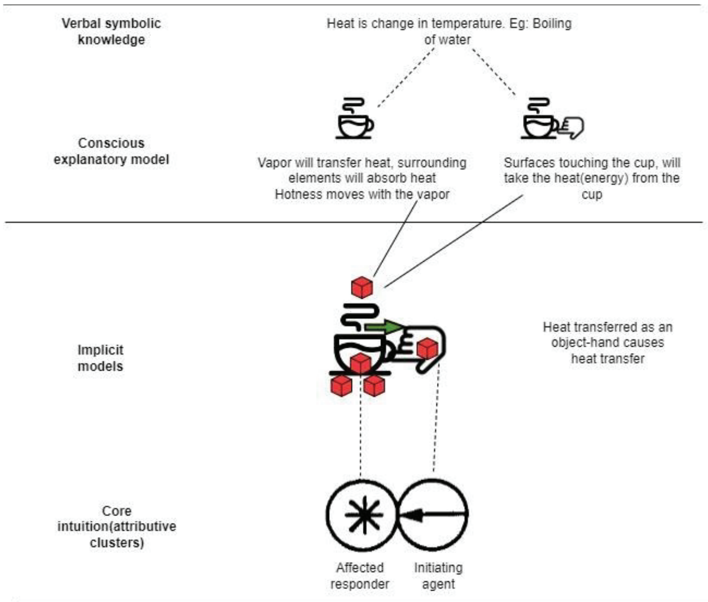

Figure 1. An example of the Framework diagram for Nash's dominant ideas in the macroscopic level activities

4. Discussion and Conclusion

From the findings of both cases, we observe how students employ diverse conceptual resources to construct scientific ideas. Nash developed a sophisticated explanatory model of heat transfer by effectively integrating his unconscious conceptual resources into his conscious thinking. Core intuitions and implicit models played a significant role throughout his sense-making process, with verbal-symbolic knowledge mainly supporting his model creation. Nash initially leaned on verbal-symbolic knowledge, using definitions of heat and temperature to initiate his reasoning. His modeling process remained predominantly conscious, using gestures and diagrams to convey his ideas. In contrast, Payal struggled to access intuitive conceptual elements and consistently relied on verbal-symbolic knowledge. While she did revise her explanatory models, research shows that successful explanatory model creation involves the incorporation of implicit models and core intuitions. Students who solely rely on verbal-symbolic knowledge or inaccurately connect it to implicit models hinder their explanatory model development (Brown & Cheng, 2010).

In both cases, students' implicit models of heat influenced their scientific reasoning about heat transfer. Students often view heat as a substance or object, aligning with early caloric theory. Previous research on high school students' misconceptions has also identified this tendency to conceptualize heat and temperature as a substance (Erickson, 1985). Payal searched for a unique aspect in heat, almost treating it as a distinct "sense." Nash, while not explicitly focusing on heat's uniqueness, also employed the notion of "sense" in explanations. These notions might hinder students' comprehension of mechanisms like heat transfer. Instead of seeking common underlying mechanisms, students become fixated on visible behaviours when reasoning (Wagner, 2006; Taber, 2010). Instructors can seize such instances to illustrate mechanistic similarities across phenomena. Students' heavy reliance on perceptual experiences, particularly in macroscopic activities, impacted their verbal-symbolic knowledge. Because heat is a phenomenological concept, rooted in sensory perception and firsthand experience, it holds more persuasive power than formal knowledge. This tendency led students to generate alternative explanations to match their observations—a trend not observed in studies on electricity or magnetism (Brown, 2017).

During the activities, Nash systematically developed ideas from various sources, integrating them across representational levels. He connected different heat transfer types in his group's model, showcasing a sophisticated understanding of heat transfer (Sunyono et al., 2015). Nash's engagement with prompts like 'my theory' and 'I need to understand' on

Knowledge Forum encouraged metacognitive thinking, leading to in-depth inquiry and refining his explanatory model (Tan & Loong, 2005). This approach could be valuable in large classrooms where individual attention is challenging. Our study highlights how students' conceptual resources influence learning about scientific phenomena, suggesting the benefit of merging intuitive and formal knowledge. Prompting students to explain divergent outcomes for similar situations can enhance their epistemic motivation (Taber, 2010). Connecting scientific principles to everyday experiences can further improve students' epistemological consistency (Lemmer et al., 2020), with potential applications in various phenomena. This article does not explore group dynamics' impact on students' resources, limiting its findings' strength within the group activity context. The analysis acknowledges potential bias in student utterances due to the interpretative approach taken. Despite considering the context, misleading interpretations are possible. The study's scope is confined to two cases; future research will encompass additional cases for robustness.

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