AC 2009-589: REPAIRING MISCONCEPTIONS: A CASE STUDY WITH ADVANCED ENGINEERING STUDENTS ON THEIR USE OF SCHEMA TRAINING MODULES

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Repairing Misconceptions: A Case Study with Advanced Engineering Students on Their Use of Schema Training Modules

Key words: misconceptions, difficult concepts, schema training

Abstract

The case study described in this paper was a formative evaluation on the adapted schema training modules and materials. The study was intended to gather feedback and suggestions from the intended audience in order to revise the training modules. The study also assessed students' overall experiences and performance regarding the tryout of the modules. Both qualitative and quantitative data were collected from the participants. Based on the case of four participants, (1) the training materials were well adapted for undergraduate engineering students; (2) the training models were effective, (3) the training modules would be more effective for students with less coursework in the engineering subjects covered by the modules.

Introduction and Background

Misconceptions

Previous studies reported that misconceptions related to heat transfer, fluid mechanics, thermodynamics, and other engineering and science concepts persist among engineering students even after they completed college-level courses in the subjects.[1- 2- 3] These misconceptions are not simple confusion or misunderstanding due to inaccurate or incomplete pieces of knowledge of the concepts.[4-5] Such misconceptions are fundamental misconceptions about differences in the way that some molecular-scale engineering processes such as the diffusion differ from other observable and macro level processes such as the blood circulation.[6]

Such misconceptions are also robust and resistant to traditional instruction because the correct understanding of some challenging concepts not only requires students' knowledge of the differences in the way they behave from commonsense conceptions but also "overcome their (perhaps even innate) predisposition to conceive" them differently.[6] To repair these misconceptions, Chi and her colleagues proposed an innovative instructional approach, ontological schema training methods, which focus on helping students develop appropriate schemas or conceptual frameworks for learning difficult engineering concepts.[7- 8- 6-9]

Ontological schema training method

The ontological schema training methods were based on assumptions about how students learn. One of the assumptions about how students learn new concepts is that students assimilate or encode new information into an existing schema or category.[10] Assimilating new information into an existing schema help students make inferences about and assign attributes to a new concept or phenomenon.[11] However, when students learn some particularly new challenging engineering concepts or processes, which are fundamentally different from their commonsense observable conceptions, they can make the wrong inference or assign incorrect attributes to the new concepts based on their existing commonsense schema. A simple everyday example is that some students think that a whale is a fish. If these incorrect inferences and attributes are not corrected, they can hinder correct understandings and be reinforced as students take more course work in the subjects. That means the misconceptions become more robust and resistant to traditional instruction. In addition, as Bereiter argues, the possibility of *missing* a particular schema or category could also cause students' making the wrong inference or assigning incorrect attributes to novel concepts or phenomena.[12] This is because when there is no existing appropriate schema to anchor the assimilating and encoding new information, students can "categorize a concept or phenomenon on the basis of its superficial perceivable features".[4] Thus, categorizing a concept and phenomenon based on superficial perceptions also results in misconceptions. In either case, helping students to build an appropriate schema for some particularly challenging concepts seems to be an effective way to repair misconceptions of difficult concepts.

Chi has identified a particular class of difficult concepts which is called Emergent Processes.[6] Emergent Processes are those properties of a system that result from its constituent elements interacting over time, often in conjunction with equilibration. Many of the concepts with which engineering students struggle can be identified as emergent processes such as heat transfer, diffusion and electricity.[6-9] Emergent process misconceptions are particularly resistant to traditional instruction because they are made at the ontological level – where students ascribe a fundamental characteristic to the concept that is at odds with the scientifically normative view.[13-6] In order to help students learn concepts of the Emerging Process ontology, instruction should first identify the ontology and provide them with some rich examples and properties of that ontology.[14- 15] This would help students develop a "schema" or mental model for that ontology which would make subsequent examples easier to understand. Referred to as "schema training," this instructional methodology has been successful with both middle school students and undergraduate psychology students.[4-15] Chi and Slotta's theoretical framework of ontology entails creating effective schema training protocols and materials that help students create appropriate mental models of important dynamic processes operating at small length scales.

Evolving new and difficult processes in engineering

Engineering is a discipline that has historically and successfully relied upon a largely empirical description of how the physical world works. As we move into the 21st century, technological advances are being made at the microscopic, molecular, and atomic levels in many fields of engineering (e.g. microfluidics, microelectronics, biotechnology, genetic engineering, nanoscale machines) that challenge engineering education to respond to these evolving disciplines. For example, a recent National Science Foundation (NSF) report calls for introducing nanoscale scientific and technology concepts into all levels of engineering and science courses so that the next generation of engineering graduates possesses a strong conceptual understanding of dynamic engineering and scientific processes at small scales.[16] Therefore, fundamentally different ways to educate engineers who will work in a global economy using next-generation technologies that rely on complex systems at small scales are critical for engineering education.

As prior misconceptions studies related to heat transfer, fluid mechanics, and thermodynamics, Miller and Streveler have found that 25-30% of the students displayed a fundamental misunderstanding about the governing mechanisms of heat transfer and that over 50% of students came to a conclusion that was in clear violation of the 2^{nd} law of thermodynamics.[1] In addition, undergraduate engineering students who had received several semesters of physics instruction still hold fundamental misconceptions of force and momentum.[17- 18]

Although literarily thousands of studies have reported student misconceptions in all areas of science and engineering, most have not contributed to the fundamental question: how can the misconception be repaired to promote deep fundamental understanding of key engineering and science concepts?[19] More recently, Chi has argued that these misconceptions are made at the *ontological* level, which requires an ontological approach.[13- 6] In other words, the most robust misconceptions occur when students mis-categorize a concept. For example, students may think of "heat" as a substance that flows from a hot to cold object instead of thinking of heat transfer as an emergent property of a system. Chi has argued that the reason some of these misconceptions are so robustly held is that students have no framework, or schema, for understanding the emergent processes of systems. [6] Chi and Slotta have investigated new instructional approaches, which are called the schema training methods, to helping students understand the complex dynamic nature of Emergent Processes, which we call the schema training methods. These schema training methods have been used with middle school children and undergraduates in non-science majors but have never been used with science or engineering undergraduates.[4-16] Since prior work has demonstrated that even advanced engineering students still hold misconceptions about fundamental concepts in the thermal sciences this paper describes the beginning of work to adapt the schema training modules of Slotta and Chi to engineering science.[15]

Purpose of the Study

The case study described in this paper was a formative evaluation on the adapted schema training modules and materials. The study was intended to gather feedback and suggestions from the intended audience in order to revise the training modules. The study also assessed students' overall experiences and performance regarding the tryout of the modules. Specifically, we were interested in the following questions:

1) Were the online schema training modules and materials appropriate for undergraduate engineering students?
2) How were the online schema training modules helpful for students learn difficult concepts?
3) How did the instruction on direct and emergent processes (i.e., schema training methods) affect students' learning and performance on the assessment questions?

Methods

Research design

This case study adopted a mixed methods design. Both quantitative and qualitative data were collected. Quantitative data were collected through an experimental design with pre and post tests on heat transfer, post tests on diffusion and microfluidics instruction. Qualitative data were collected through semi-structured interviews and open-ended questions asking for students' justification of their answers to the multiple choices questions. The qualitative data were intended to triangulate the quantitative data. Soliciting students' verbal justification was intended to identify students' inferences and attributes to either the direct processes (i.e., commonsense conceptions) or the emergent processes.

Four mechanical engineering students (n=4) were selected from a pool of volunteers with preference given to those who took at least one course in thermodynamics, heat transfer and/or fluid dynamics. The following table (see Table 1) lists the kind of coursework each participant has completed. Two participants were female and two were male. Three participants were Caucasian and one was Asian. Two of the participants were seniors, one was a sophomore and the other was a first year masters' student.

Table 1 - Coursework Taken by Participants

	Participant	Fluid Dynamics	Heat Transfer	Thermodynamics
Experimental Group	1			x
	2	x		x
Control Group	1	x	x	x
	2	x		x

Two students were randomly assigned to an experimental group and the other two were assigned for the control group. Both experimental and control groups received the same instruction on diffusion, heat transfer, and microfluidics. All training materials (modules) were hosted in Blackboard (a course management system) and were self-paced. However, the experimental group was also given the instruction on the emergent process, which is one of the two classes (emergent vs. direct) of conceptual phenomena that cause students' misconceptions. In addition, the experimental group also had an extra section on diffusion, which specifically mapped the diffusion concepts to the emergent processes. It should be noted that the microfluidics text was included as a far transfer, which was intended to assess whether students could apply what they learned about the direct and emergent processes in different situations other than those illustrated in the training modules. After the participants finished their modules, they were interviewed regarding their perceptions and feedback on the overall experience with the schema training modules. The following table (Table 2) illustrates the design procedures of the case study.

Table 2 - Procedures of the Case Study (highlighted areas are those areas where experimental and control modules differ)

Procedure	Experimental Group	Control Group
Demographic Questions Survey	Demographic Information	
Pre-Test	Heat Transfer	
Training Module	The Direct and Emergent Processes: Part I (Diffusion as an emergent process)	The Nature of Science (Diffusion example with **no** mention of diffusion as an emergent process)

Table 2 - Procedures of the Case Study (highlighted areas are those areas where experimental and control modules differ) (continued).

Procedure	Experimental Group	Control Group
Target Instruction	Heat transfer with a reminder that it is an emergent process	Heat Transfer with **no** mention of it as an emergent process
Test for Understanding	Diffusion	
Post-Test	Heat Transfer (repeated measure)	
Far Transfer Instruction	Microfluidics	
Test for Understanding	Microfluidics	
Interview	Semi-structured Interview	

Training materials

The online schema training modules or materials for the experimental group consisted of the Direct and Emergent Processes: Part I and the Direct and Emergent Processes: Part II. The purpose of Part I was to build a general understanding of the nature of the two different processes, direct and emergent processes. Part I introduced these two kinds of processes with different examples and was embedded with two computer simulations on diffusion. It also described the similarities and differences between the two kinds of processes including ways to identify them. Simply defined, a direct process is a process that "has an identifiable agent that causes some outcome in a sequential and dependent sort of way".[4] Main properties of direct processes in terms of the pattern and trend of the outcome are: "causal and intentional agents," "alignment," "sequential and dependent," "differentiated behavior or actions," which characterize a direct process.[4] However, an emergent process is a process that "results from the collective and simultaneous interactions" of all agents or elements forming the process.[4] Main properties of emergent processes in terms of the pattern and trend of the outcome are: "undifferentiated or uniform" interactions, the interactions occur "simultaneously" and "randomly," and have no identified cause of behavior. Finally, Part I illustrated the direct processes with two examples of "building a skyscraper" and "wolves hunting" and emergent processes with "crowd forming a bottleneck" and "fish schooling". Part II discussed heat transfer and microfluidics and was embedded with two computer simulations on heat transfer and one video clip on microfluidics.

The online schema training materials for the control group consisted of the Nature of Sciences and Thermo-fluid Processes (which was exactly the same as the Direct and Emergent Processes: Part II for the experimental group). The Nature of Science described the scientific world view, the inquiry process, and the scientific enterprise. In addition, it also included the diffusion instruction but without the mapping back to emergent processes instruction. The diffusion instruction in the Nature of Sciences module also included the same two computer simulations as those in Part I. The Direct and Emergent Processes Part I and the Nature of Science were approximately equivalent in terms of the number of words and figures. For example, Part I had 8341 words and 11 figures while The Nature of Science had 7342 words and 17 figures. For all three different modules, there were open-ended reflection questions inserted after each main section of instruction in order to facilitate students' deep understanding of the training materials.[20]

Results

Adaption of the schema training modules

Results of the case study indicated that the materials, which were originally used to train middle school students and undergraduate psychology students in learning science concepts, were well adapted for undergraduate engineering students. Specifically, all four participants (n=4) considered the reading level of the modules is appropriate for undergraduate engineering students, the content is accurate and up to date, and the modules are visually appealing. In addition, both participants in the experimental group concluded that the instruction in Direct and Emergent Processes: Part I was helpful for them to understand diffusion, heat transfer, and microfluidics concepts.

Effectiveness of the schema training modules

In this case study, the two participants in the experimental group performed better on all three sets of assessment questions (diffusion, heat transfer, and microfluidics) than the two participants in the control group did. The three sets of questions for heat transfer, diffusion and microfluidics were chosen from the Thermal and Transport Concept Inventory (TTCI), which was designed to detect students' misconceptions.[21] The heat transfer assessment had 18 multiple choices questions, the diffusion assessment had 20, and the microfluidics assessment had five. Although all four participants have taken at least one course in thermodynamics, heat transfer and/or fluid dynamics, none of them correctly answered all the diffusion, heat transfer, or microfluidics questions. The following table (see Table 3) summarizes the overall performance on the assessment tests with multiple choices questions for each participant on diffusion, heat transfer, and microfluidics. (The heat transfer statistics in Table 2 were based on the participants' performance on the post test.)

Table 3 - Participants' Overall Assessment Performance on Multiple Choices Questions

Participant		Heat Transfer (% correct)	Diffusion (% correct)	Microfluidics (% correct)
Experimental Group	Sophomore	72	90	80
	Senior	39	90	60
Control Group	Senior	44	40	40
	1st year master's student	22	65	60

Since none of the participants correctly answered any of the three sets of multiple choices questions, their performance on these assessment questions demonstrated that misconceptions existed in this group of four engineering students. This finding is consistent with prior misconception studies for undergraduate engineering students.[1- 2- 3]

Effectiveness of the schema training methods

It was interesting to note in this case study that students who had more coursework seemed to do worse on the assessment questions for diffusion, heat transfer, and microfluidics. For example, one of the experimental group students who only took one course in thermodynamics (see Table 1) had the best performance for all three sets of assessment questions on diffusion, heat transfer, and microfluidics. Thus, based on this four participants course work in the subjects might have reinforced students' misconceptions for some particular concepts. This finding was also confirmed through the students' interviews. As one student reflected:

> …the direct and emergent processes instruction was helpful for me to understand the heat transfer, diffusion and microfluidics concepts. However, I don't think my answers to the assessment questions changed that much because I've taken all the courses already. I think the [direct and emergent processes] instruction is more helpful for someone who has not taken any related courses…

In addition, according to the four participants' performance on the assessment questions, the approach of mapping a difficult engineering concept to emergent processes other than providing domain-general (not focusing on teaching specific technical details about any science process) instruction on the emergent processes seemed to be most effective to help repair students' misconceptions. For example, the diffusion instruction was specifically mapped back to the emergent processes for the both participants in the experiment group, but no such mapping was done for the control group. Consequently, both participants in the experimental group seemed to have performed much better (90 % correct answers) than the control group participants did. While for the heat transfer and microfluidics instruction, there was no specific mapping back to the emergent processes. Consequently, there seemed to be no discreet difference, in terms of the correct percentage of assessment questions (see Table 3), between the two groups' performance on the assessment of heat transfer and microfluidics.

We also analyzed all students' justifications of their answers to the multiple choices questions for the six microfluidics open-ended assessment questions. If the training in emergent processes was useful, we would expect to see that both participants in the experimental group were better able to understand the microfluidics questions. And the experimental group did provide more correct verbal explanations for the multiple choices questions. Both participants in the experimental group provided four correct explanations (n=4) (4/6) while each of the two control group participants only had one correct explanation (n=1) (1/6). Further analysis of the verbal explanations indentified the inferences and attributes to some emergent processes by the experimental group participants' and inferences and attributes to direct processes by the control group participants. For example, one of the participants in the experimental group who did not take any fluid dynamics courses wrote "I was told earlier that fluid molecules will always take a *random* path. If this holds true, than the particles will diffuse, even if it isn't much." which demonstrated that he mapped back his rationale of the choice of answers to the emergent processes instruction. For the control group, the incorrect answers had more commonsense and observable attributes such as: “travel” “mixing” “gravity” which is close to weight instead of attributes of “diffuse” and “random”.

Conclusion and Implications

This case study reports four students’ performance, perceptions, and feedback regarding the instructional design (interface, and usability, spelling, the accuracy of information, etc.) and the effectiveness of the schema training modules and schema training methods. The outcomes of this case study provided some evidence from engineering students about the effectiveness of schema training modules and a small group of target students’ perceptions and feedback on using the schema modules. Based on the case study with four participants, the schema training modules were well adapted for undergraduate engineering students. The training modules and training methods were effective and helpful for students understand some challenging concepts of heat transfer, diffusion, and microfluidics. The case study also helped us to refine the implementation of the training materials, as student fatigue seemed to have an impact on our results. However, since this is a case study with a small target audience (n=4), more data and information are needed to understand why such misconceptions exist and how to repair them. The collection of much more data is our next step in the study.

Key contributions of this study are to develop and validate instructional methods that will repair student misconceptions of fundamental engineering concepts. Such a study could lead to transformational approaches to repair students’ misconceptions by applying and testing that ontological schema training methods can help repair robust misconceptions, which are resistant to repair by traditional teaching methods.

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