The Search for Strategies to Prevent Persistent Misconceptions

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Abstract

Research shows that it may be too late to repair misconceptions of fundamental science and engineering concepts by the time students reach core engineering courses. Therefore, we need to focus on preventing such misconceptions. This paper reports the Stage One outcomes of a larger study: A synergistic approach to prevent persistent misconceptions with first-year engineering students. It addresses the following two aspects: (1) misconception repair strategies have had weak results, and (2) a synergistic approach that focuses on preventing/eliminating misconceptions. This paper has implications for new direction and effort in studying student misconceptions and promoting conceptual changes, which is to focus on preventing misconceptions from forming.

Introduction

Research shows that it may be too late to correct and repair misconceptions of fundamental science and engineering concepts by the time students reach core engineering courses. [1, 2] For example, it is quite common that engineering juniors and seniors have misconceptions related to concepts in heat transfer, fluid mechanics and thermodynamics even after they have completed college-level courses in the subjects. [3, 4]To date there is no single strategy that could successfully repair all misconceptions. [5, 6] If efforts on repairing misconceptions did not achieve intended goals, [7] new approaches to prevent misconceptions seem to be logical and should be the most economic way to pursue.

Students can have misconceptions long before arriving at college. Therefore we propose focusing on eliminating misconceptions and teaching students how to prevent them from forming earlier in their college experience. We acknowledge that there are different types of misconceptions. Some misconceptions are due to simple confusion or misunderstanding whereas some are due to a lack of information or knowledge of concepts. [8] Others are fundamental misconceptions about differences in the way that some small-scale engineering processes such as molecular level diffusion differ from other observable and macro level processes for instance blood circulation. The first two types of misconceptions (simple confusion and lack of information or knowledge) are relatively easier to treat at the time when a misconception is spotted. However, fundamental misconceptions persist and are difficult to change.

In this paper we focus on those fundamental misconceptions that are persistent and difficult to change. We report the Stage One outcomes of a larger study: A synergistic approach to prevent persistent misconceptions with first-year engineering students. The paper addresses the following two aspects: (1) misconception repair strategies have had weak results, and (2) proposing a synergistic approach that focuses on preventing/eliminating misconceptions from forming.

Strategies for repairing misconceptions

From the review of previous studies on student misconceptions of science and engineering concepts and conceptual change, we found most strategies for treating student misconceptions focus on repairing and changing misconceptions when they have already been formed or identified. Among these remedy strategies, four strategies are most frequently adopted and tested: (1) using conceptual conflict to confront and contradict misconceptions, (2) using computer simulations to promote conceptual changes, (3) inquiry-based activities (such as problem-based learning) to promote conceptual changes, and (4) presenting four conditions of the Conceptual Change Model to promote conceptual changes.

Another newly emerged strategy is the schema training approach which trains students on emergent and sequential processes, separately. The goal of the schema training is to facilitate the formation of new mental representations of these two different processes. [8, 9] Emergent processes are ontological attributions or properties of a system that result from its constituent elements interacting over time in a random and simultaneous pattern, often in conjunction with equilibration. [8, 9] Sequential processes are also ontological attributions or properties of a system that result from its elements or agents of the process, but acting and interacting in a causal and dependent pattern. The following table lists major distinctions between the two scientific processes. [8]

Table 1. Differences between emergent and sequential processes.

Emergent Processes	Sequential Processes
Elements interact in a *"uniform or indistinguishable"* manner.	Elements can have various *"distinguishable"* interactions.
Elements interact in an *"unrestricted"* manner.	Elements are *"restricted"* in terms of other elements they can interact with.
Interactions occur *"simultaneously"*.	Interactions occur *"sequentially"*.
Interactions are *"independent"* of each other	Interactions *"depend"* on other interactions.
Interactions *"continue indefinitely"*.	Interactions can *"terminate"*.

The schema training approach assumes that possessing mental representations of emergent and sequential processes will facilitate subsequent learning of difficult concepts and promote conceptual changes. This approach seems to be promising for repairing misconceptions in different subjects and across student levels (K-12 and college). However, it works better with middle school students than college students. The following table illustrates all five strategies adopted/tested/reviewed in specific studies or report on repairing misconceptions in science and engineering education. For studies (other than a review paper), the level of participants is also listed.

Table 2. Remedy strategies for repairing misconceptions.

Strategy	Study/Review	Concept	Participant Level	Outcome
Using conceptual conflict to confront and contradict students' misconceptions and inducing students to reflect on their conceptions	Hewson & Hewson [10]	Mass, volume, density and speed	N/A	Effective
	Tao & Gunstone [11]	Force and motion	K-12 (Grade 10)	Mixed outcomes (some participants achieved conceptual changes and others did not)
	Trumper [12]	Energy	K-12 (Grade 9-11)	Ineffective
Using computer simulations to facilitate conceptual change and correct misconceptions	Windschitl & Andre [13]	Human cardiovascular system	College	Effective
	Tao & Gunstone [11]	Force and motion	K-12 (Grade 10)	Mixed outcomes
	Carlsen & Andre [14]	Electric circuits	College	No greater effect when combined with another method
Inquiry-based approach	McDermott [15]	Electric circuits	College	Effective
	Nottis, Prince, & Vigeant [16]	Heat transfer and thermodynamics	College	Effective
	Miller et al. [17]	Heat transfer	College (Junior/senior)	Ineffective
Presenting conditions of CCM: (1) dissatisfied with current conceptions & find a new conception (2) intelligible; (3) plausible and (4) fruitful	Duit [6]	Supposed to be effective in all subject areas	N/A	Not as effective as the CCM intended to be
Using schema training approach to train students on two scientific processes (domain-general)	Miller et al.[17]	Diffusion	College (Junior/senior)	Effective
		Microfluidics		Effective
		Heat transfer		Ineffective
	Berg [18]	Diffusion and osmosis	College	Effective
	Chi et al. [19]	Diffusion	K-12 (Grade 8 & 9)	Effective
		Heat transfer		Effective
	Slotta & Chi [20]	Electricity	College	Effective

While our review of existing research on repairing misconceptions and promoting conceptual changes found some strategies effective, to date there is no single strategy that could successfully repair all misconceptions. If we can prevent students from forming misconceptions of core concepts in the first place, we can not only help students better learn science and engineering concepts, but also save precious resources devoted to repairing misconceptions later on. Through this approach we believe we can increase the numbers of students pursuing degrees and careers in science and engineering fields at large.

A synergistic approach to preventing/eliminating misconceptions

Many misconceptions of difficult concepts including heat transfer with which engineering students struggle can be identified as misconceptions of emergent processes that are particularly resistant to instruction. [8, 21] Students usually reveal their misconceptions of difficult engineering concepts when referring attributes of emergent processes to those of less complex sequential processes. Students have such misconceptions because they lack appropriate mental representations of more complex emergent processes. [21] Based on outcomes of reviewing previous studies, we propose a *synergistic approach* that utilizes effective instructional design and the development of student mental representations of fundamental yet difficult concepts with first-year engineering students. The synergistic approach is aimed at preventing and eliminating misconceptions before students take relevant coursework. The approach consists of (1) utilizing interactive learning strategies enhanced by educational technology, (2) training students on mental representations of scientific processes (SPs) (domain-general training), and most importantly (3) explaining difficult concepts in the language of SPs (domain-specific) in addition to the domain-general training on SPs.

Providing domain-specific training on SPs will provide a concrete context for students and make students' learning new and difficult concepts easier as well as shorten the time for forming correct conceptual understanding. This approach harnesses the synergistic effect of both domain-general and domain-specific training. The idea of providing domain-specific training on SPs was inspired by a recent study in which the students performed statistically different (better) on the assessment test when diffusion concepts were simply referred to as emergent process. [2, 17]

We believe that explaining difficult concepts in the language of SPs in addition to the domain-general training of SPs will be the most effective instructional method to provide a strong, appropriate foundation of conceptual understanding to prevent first-year engineering students from forming stubborn misconceptions. Stage Two of the large study will examine this *synergistic approach* using an experimental design study and a follow-up study with first-year engineering students, which is currently undergoing.

Discussions and conclusion

Persistent misconceptions as those of heat transfer are often resistant to remedy (repairing) strategies once they are identified due to a couple of reasons. First, the correct understanding of challenging concepts not only requires students' knowledge of differences in the way the concepts behave from common sense conceptions but also "overcome their (perhaps even innate) predisposition to conceive" (p. 161) them differently. [8] Second, some coursework or instruction actually reinforces misconceptions and results in the formation of a learning impediment. [2] For most senior undergraduate engineering students who had taken several courses in thermo-fluid sciences over several semesters, their knowledge in the subject area has already firmly rooted in their cognitive mental structure. This is when it is very difficult and even not practical to correct and change such misconceptions because it is so easier and convenient to think the way one used to instead of using new mental representations a remedy effort promotes.

Furthermore, even if we reap the initial success of remedy interventions and students appear to accept the new scientific view, most revert to their old conceptions and regress to misconceptions after a period of time. [11, 22] The finding that the more coursework students had, the worse they performed on relevant assessment tests [2] best illustrates this persistent issue from the perspective of a learning impediment. Therefore, for misconceptions of core engineering sciences that are prevalent and persistent documented by multi-institutions among undergraduate engineering students, [1] a more rational way for us to treat them is to prevent them by training students before they take relevant coursework.

The nationwide trend to reduce the number of credit hours in engineering education have resulted in a compact and refined curriculum, leaving less time for remedy interventions. We believe a foundational understanding of core science and engineering concepts early in the curriculum is more critical than ever for students to succeed in upper level engineering courses and improve their problem-solving abilities for multidisciplinary projects. Therefore, we believe preventing and eliminating student misconceptions can be a key strategy to increase retention rates in engineering degrees.

Acknowledgement

We thank the National Science Foundation (NSF) for supporting this project: A Synergistic Approach to Prevent Persistent Misconceptions with First-year Engineering Students (EEC-1232761). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

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