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More than the Ideas Themselves: Influence of Student Attributes in Conceptual Change

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Abstract: *Research in science education and cognitive psychology has identified many variables that influence conceptual change in science. We are developing a synthetic model that examines the relative contributions to conceptual change of variables drawn from both bodies of research. We describe our hypothetical model and pilot results from undergraduate biology.*
Keywords: *conceptual change, science education, motivation*

Much of the research into conceptual change, specifically in science education, has focused on the content of student ideas and on instructional approaches to move students from naïve ideas to more canonical ideas in a field (e.g., Bransford et al., 2000; Hammer, 1996). Yet there is a growing awareness that even when instructors use research-based teaching strategies designed to address specific misconceptions[1], many students still leave introductory undergraduate science courses with their misconceptions intact (e.g., Authors, 2013; Bishop & Anderson, 1990; Nehm & Reilly, 2007). Solely addressing students' naïve ideas appears to be often insufficient; additional variables besides instruction appear to influence whether or not individual students recognize their misconceptions and reach a correct understanding of science concepts.

Research in other areas, particularly in social and cognitive psychology, has provided evidence that changing student conceptions involves more than students' ideas themselves—conceptual change is influenced by student and contextual attributes (Pintrich, Marx, & Boyle, 1993). For example, students must be motivated to do the thinking required to change misconceptions (Dole & Sinatra, 1998; Sinatra & Pintrich, 2003).

There have been calls to examine conceptual change using a multi-perspective framework, one that merges cognitive, individual, and social perspectives (Dole & Sinatra, 1998; Duit & Treagust, 2003). Such a framework would include variables from more than one perspective, including for example, aspects of motivation, epistemic beliefs, cognitive and metacognitive strategies, formal reasoning abilities, science content knowledge, and instructional strategies. Variables from all of these categories have been empirically shown to influence conceptual change. For example, Qian & Alvermann (1995) found that high school science students who believed knowledge was a collection of discrete facts (an immature epistemic belief termed "simplicity of knowledge") were less likely to experience conceptual

[1]Several terms have been used to describe student misunderstandings in science, including "misconception," "naïve conception," and "alternate conception." We have chosen to use "misconception" because it is the preferred term in the undergraduate education research community (National Research Council, 2012).

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change than those who had more sophisticated beliefs. Linnenbrink-Garcia, Pugh, Koskey, and Stewart (2012) found an interaction between interest, self-efficacy, and prior knowledge in conceptual change in high school biology. Anderson and Nashon (2007) described an interaction between self-efficacy and metacognitive skills in conceptual change in high school physics. Taasoobshirazi and Sinatra (2011) found that among undergraduate physics students, motivation influenced conceptual change.

A review of the literature, however, shows there is limited evidence that any of these variables play a consistent or important role in conceptual change. None of the variables have been studied in more than a few classrooms (at least in regard to how they influence conceptual change), and the grade levels and subject areas examined in this research have varied greatly. There have been no systematic reviews of how strongly or how often these variables affect conceptual change in college science classrooms. Furthermore, very few studies have looked at more than one category of variable at once.

Table 1. *Seven categories of 34 variables proposed to affect conceptual change in undergraduate biology.*

Category	Variable	Category	Variable
I. MOTIVATION	1. Intrinsic motivation 2. Self-efficacy 3. Grade motivation 4. Career motivation 5. Performance avoidance	V. BIOLOGY CONTENT KNOWLEDGE	21. Genetics 22. Ecology 23. Individual variation 24. Organismal diversity 25. Anatomy
II. EPISTEMIC BELIEFS	6. Innate ability 7. Learning quick 8. Simple knowledge 9. Certain knowledge	VI. DEMOGRAPHICS	26. Age 27. Sex 28. Race 29. Grade 30. Major 31. Highest educational attainment of parents
III. COGNITIVE & METACOGNITIVE STRATEGIES	10. Rehearsal 11. Elaboration 12. Organization 13. Critical thinking 14. Self regulation 15. Cognitive reflection	VII. INSTRUCTION	32. Misconception knowledge (of teacher) 33. Teaching for conceptual change 34. Assessment type
IV. FORMAL OPERATIONAL REASONING	16. Proportional 17. Probabilistic 18. Hypothetico-deductive 19. Correlational 20. Control of Variables	VIII. LEARNING	35. Conceptual change regarding natural selection 36. Course grade

Our research program's larger goal is to develop a synthetic model that describes how aspects of motivation, epistemic beliefs, cognitive and metacognitive strategies, formal operational reasoning, biology content knowledge, and demographics interact with instruction to influence conceptual change in introductory undergraduate biology courses. We are beginning a research project to collect data on these variables in 60 university biology courses across the United States, and will use structural equation modeling to establish the relative contributions to conceptual change of the 34 variables in Table 1. In preparation for this large-scale study, we are conducting preliminary studies in undergraduate biology learning to explore contributions of selected variables and interactions. In this paper, we present preliminary results of our work: our hypothetical structural model, and the pilot data collected in an undergraduate environmental science course.

HYPOTHETICAL STRUCTURAL MODEL

Structural equation modeling requires specification of a model based on theory (Klem, 2000). Figure 1 presents the preliminary research-based model of conceptual change that we will test through structural equation modeling.

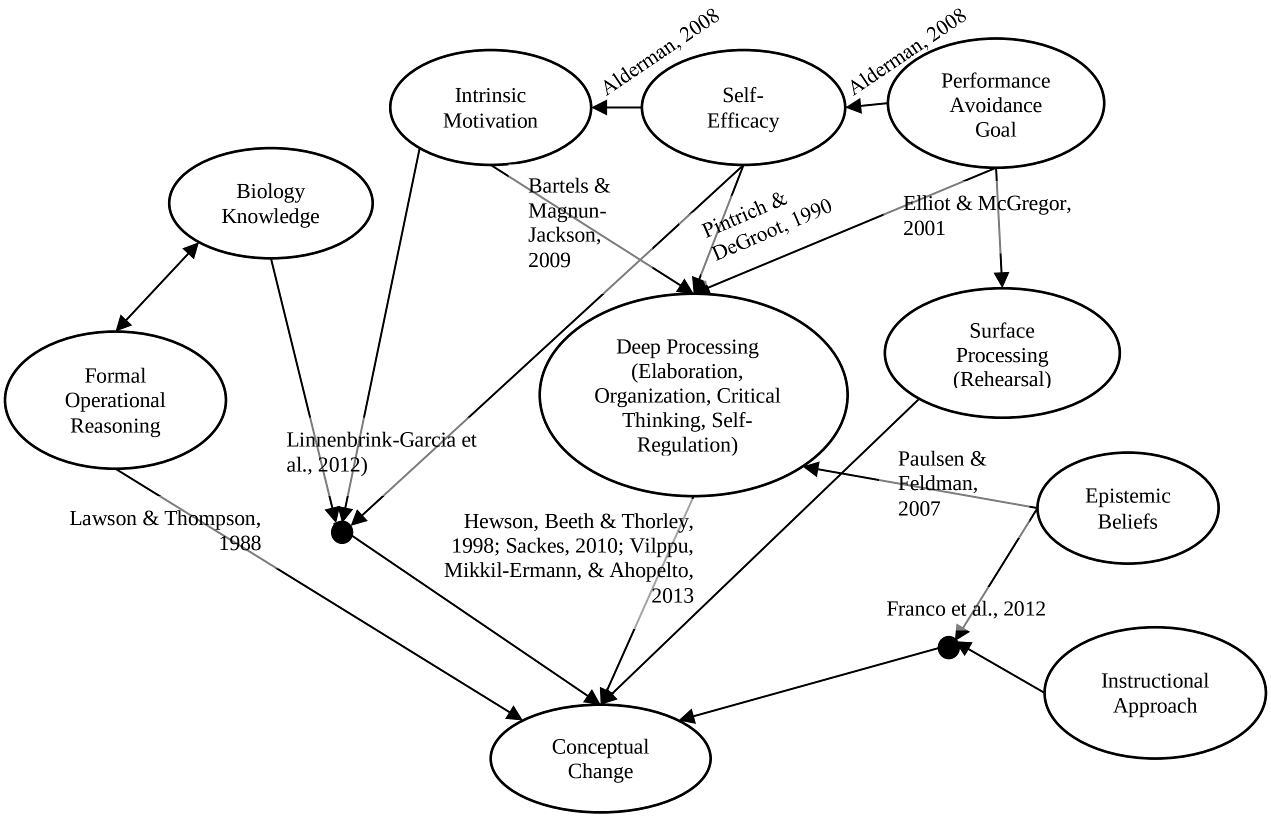

Figure 1. Structural model reflecting latent (unmeasured) variables in ovals and hypothesized direct effects in arrows between ovals. Solid black circles indicate interactions between variables. This is one preliminary hypothetical model that will be tested using structural equation modeling.

PILOT DATA COLLECTION AND RESULTS

We conducted a pilot study to gain information about our planned data collection instruments and to begin to investigate relationships between variables in our hypothetical model. We collected data in a freshman-level environmental science course from 123 students (sex: 63% male, 37% female; major: 68% science, 25% non-science, 7% undecided; class standing: 46% freshman, 28% sophomore, 16% junior, 10% senior). This study examined the influence of 16 student variables (variables 1-4, 6-7, 10-14, and 16-20 from Table 1) on conceptual change in environmental chemistry topics. We calculated conceptual change as the difference between post- and pre-instructional scores on a four-item test (Table 2) constructed by the second author, who was the course instructor. We assessed the student variables at the time of the pre-test, using established instruments drawn from the literature: Science Motivation Questionnaire II (Glynn et al., 2011) for motivation, Motivated Strategies for Learning Questionnaire (Pintrich et al., 1991) for metacognitive and cognitive variables, and Classroom Test of Scientific Reasoning (Lawson, 1978; Lawson et al., 2000) for formal operational reasoning. To measure epistemic beliefs, we drew items from the Epistemic Beliefs Inventory (Schraw, Bendixen, & Dunkle, 2002) and the Epistemological Beliefs Survey (Wood & Kardash, 2002), in addition to modifying items from these instruments to get at beliefs we posited would be more specific to the requirements of conceptual change.

Table 2. *Pre- and post-instructional environmental chemistry questions to assess conceptual change.*

Multiple-choice Questions and Responses	
Consider a log burning in a campfire. What happens to most of the material the log is made of as it burns? a. It is turned into ashes. b. It is turned into heat and light. *c. It is turned into an invisible gas. d. It is consumed and disappears.	A child eats a hamburger. What happens to the atoms in the hamburger after it is eaten? a. Some of the atoms are turned into energy. b. Some of the atoms are turned into different atoms the body needs. *c. The atoms are separated and combined in new ways. d. None of the above.
Consider a rabbit and a lump of coal. What is the difference between the substance that each is made of? a. A lump of coal and a rabbit are made out of fundamentally different substances. *b. A lump of coal and a rabbit are made out of similar substances, but arranged differently. c. Rabbits have a vital essence that gives them life. d. Nobody knows.	A glass of water is placed outside on a sunny day until all of the water disappears. What happened to the water? a. It turned into air. b. It broke apart into oxygen and hydrogen. *c. It moved into the air. d. None of the above.

*Correct answer

There was evidence that students in the pilot study did undergo conceptual change (pre-test M=1.5, SD=1.17; post-test M=2.9, SD=1.02). Yet none of the student variables we measured were related to conceptual change (correlation matrix presented in Figure 2). All five formal operational reasoning variables, as well as the epistemic variable of "learning is quick or not at all," however, had statistically-significant, low-to-moderate positive relationships with course grade. In addition, the pilot data showed statistically significant relationships among motivation, epistemic beliefs, and cognitive and metacognitive variables. Only one relationship between a formal operational reasoning variable and a student variable from another category was significant at $p < 0.01$: a low-to-moderate positive relationship between control of variables skill and intrinsic motivation (interest).

Variable	1	2	3	4	6	7	10	11	12	13	14	16	17	18	19	20	35	36
1 Intrin Mot	-																	
2 Self-Effica	.645**	-																
3 Grade Mot	.498**	.683**	-															
4 Career Mot	.732**	.598**	.463**	-														
6 Innate	.193*	.327**	.376**	.186*	-													
7 Quick	.060	.237**	.195*	.050	.458**	-												
10 Rehearsal	.124	.195*	.252**	.166	.191*	.188	-											
11 Elaborat	.304**	.318**	.207*	.244**	.226*	.141	.449**	-										
12 Organiza	.219*	.306**	.342**	.295**	.197*	.078	.552**	.537**	-									
13 Crit Think	.463**	.256**	.087	.363**	.115	.069	.213*	.510**	.264**	-								
14 Self-Reg	.417**	.395**	.337**	.317**	.281**	.145	.531**	.636**	.584**	.504**	-							
16 Proport	.021	.118	.052	.100	.137	.131	.028	.165	.017	.091	.104	-						
17 Probabil	.077	.192*	.148	.056	.115	.206*	-.062	.019	-.065	-.095	.029	.278**	-					
18 Hyp-ded	.112	.162	.064	.171	.125	.196*	-.096	.123	.033	.078	-.036	.328**	.146	-				
19 Correlat	.160	.115	.068	.157	.032	-.003	-.135	-.001	-.054	.015	-.049	.207*	.260**	.141	-			
20 Cntrl Var	.249**	.118	.043	.203*	.134	.193*	.045	.147	-.055	.158	.089	.398**	.327**	.427**	.253**	-		
35 Cncpt Chg	-.061	-.108	.004	-.031	-.028	-.032	.096	.098	.044	.015	-.037	-.092	-.023	-.144	.111	.007	-	
36 Crse Gde	-.012	.122	.078	.061	.072	.229*	-.054	-.048	.021	-.050	-.055	.342**	.199*	.225*	.275**	.245**	.125	-
Max score	20	20	20	20	15	15	16	24	16	20	48	4	4	4	2	6	4	100.7
Mean	16.0	15.4	17.1	16.1	11.2	11.0	9.7	16.2	9.4	12.1	28.1	2.0	3.3	2.0	1.4	3.7	1.4	90.6
Standard Deviation	3.18	3.08	2.61	4.57	1.85	2.11	2.89	3.55	3.19	3.71	6.19	1.57	1.18	1.31	0.82	1.76	1.27	6.30
Coefficient of Variation	0.20	0.20	0.15	0.28	0.16	0.19	0.30	0.22	0.34	0.31	0.22	0.78	0.35	0.66	0.60	0.48	0.89	0.07

Figure 2. Correlation matrix and descriptive statistics of student variables, conceptual change, and course grade. **Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed). Epistemic belief variables (6&7) were scored so that high scores represented sophisticated beliefs. Numbers associated with Variable names are from Table 1. Coefficient of Variation = Standard Deviation/ Mean

Discussion

At first glance, the absence of correlations between student variables and conceptual change is surprising and discouraging. Yet as a pilot study, it provides valuable information before we undertake a large-scale data collection. The results generated several hypotheses that we will explore through additional rounds of pilot study. Specifically, we posit that correlations may not have been detected because: the chemistry test may not have allowed sufficient differentiation among student scores, there may not have been sufficient variation among students in measurements of student variables, the validity of instruments used may not be adequate, we may not have identified and measured the most relevant factor for conceptual change (for example, attendance), or the variables we measured were not relevant to conceptual change in this course or for this topic. Furthermore, the course instructor was a science education researcher attuned to misconceptions and conceptual change instructional strategies, thus results in his course may not be representative of typical introductory biology courses, something we could only determine by collecting data from courses that vary in terms of instructional approach.

Previous research has identified the variables we investigated as being important to conceptual change. Yet it is not a forgone conclusion that these variables are important in all classrooms, at different levels, or in different subjects. The story is not as simple as even we thought (and we already thought it was complicated). Our results indicate we need further piloting of instruments and further development of a theory-based hypothetical model in order to develop a synthetic model of conceptual change. Our preliminary results indicate the importance of testing many variables in many courses, and underline the need for the larger data collection on which we are embarking (60 courses, 34 variables).

While we have more work to do before we achieve a synthetic model, such a model would have implications for undergraduate science instruction. For example, a model may identify the importance of helping students to realize that understanding a topic takes time and effort on their part (cognitive and metacognitive strategies, epistemic beliefs). Establishing which variables have the strongest relationships to conceptual change may help instructors focus their efforts where they can expect the most impact. For example, if motivation is strongly related to conceptual change, instructors could improve student learning by drawing on instructional models designed to increase motivation. Finally, the model we develop for understanding natural selection concepts could be tested for other concepts in biology and in other areas of science (for example, physics), and thereby guide instructors across science subjects.

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