Models of Expertise in Process- and Content-Dominated Areas of Bioengineering

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Abstract: We examine expertise as an assemblage of factual knowledge, conceptual knowledge, and the ability to transfer. Experiment 1 provides empirical support in biomechanics, a content-dominated domain; Experiment 2 extends the construct to bioengineering design, a process-dominated domain. Factual knowledge is a lesser predictor than conceptual knowledge, which is a lesser predictor than transfer in determining level of expertise. This study instantiates a view of expertise that held broad appeal but lacked empirical evidence.

A Model of Expertise

The development of expertise has been framed as requiring: (a) a deep foundation of factual knowledge, (b) a conceptual framework, and (c) organization to support retrieval and use (Bransford, Brown, & Cocking, 2000). This view is modeled in the context of biomechanics (Pandy, Petrosino, Austin, & Barr, 2004). The control group received a lecture and worked problems and the experimental group completed challenge-based instruction modules (Schwartz, Lin, Brophy, & Bransford, 1999). Changes in student achievement were quantified using pretest and posttest questionnaires designed to measure changes in three facets of expertise (a) factual knowledge, operationalized as use of key facts and principles; (b) conceptual knowledge, operationalized as use of underlying principles and equations; and (c) transfer, operationalized as application of knowledge to new situations. A model was posited as a weighted, linear combination of factual knowledge, conceptual knowledge, and transfer. Transfer was weighted most heavily (50%), with the remainder divided between conceptual knowledge (40%) and factual knowledge (10%). The weightings were chosen to reflect one of the main tenets of this synthetic view: The ability to grasp key concepts (conceptual knowledge) and to apply those concepts in solving novel problems (transfer) is much more important to the development of expertise than is the ability to recall facts. Thus, expertise in biomechanics was hypothesized as Model 1: $E = 0.10F + 0.40C + 0.50T$, where E = expertise, F = factual knowledge, C = conceptual knowledge, and T = Transfer.

Experiment 1: Empirical Derivation of the Model

The model is an expression of theoretical beliefs that, while compelling, are not supported empirically. The data for the empirical derivation are those collected during the theoretical derivation. These data are changes from pre to posttest along three facets of expertise: (a) factual knowledge; (b) conceptual knowledge; and (c) transfer. The groups' scores were compared using two-group multivariate analysis of variance (MANOVA).

Results

The experimental group ($M = 1.73$, $SD = 1.10$) achieved significantly higher transfer gains than the control group ($M = 0.40$, $SD = 0.70$) ($F = 10.57$, $p = 0.00$) and this is associated with high power (power = 0.87). There was no significant difference in conceptual knowledge ($F = 0.92$, $p = 0.35$) or factual knowledge ($F = 3.10$, $p = 0.09$). The linear combination that maximally separated the two groups is Model 2: $E = 0.14F - 0.36C + 1.27T$. When contrasted with the theoretical model, $E = 0.10F + 0.40C + 0.50T$, the relative magnitudes of the weights share the same ordinal trend ($F < C < T$). The weight for transfer, as compared to the theoretical model, is much larger, suggesting that the original model underestimated the importance of this facet. The derived weighting for conceptual knowledge is reversed from the theoretically proposed weighting, meaning that when controlling for the gains in factual knowledge and transfer, higher scores on conceptual knowledge yield lower differences between the groups.

Experiment 2: Extending the Model to the Context of Design

We extend the domain to bioengineering design, which provides a contrast between primary focus on explicit learning to implicit learning in the presence of content (Goel, 2000). While most of the problems in Experiment 1 could be solved via reliance on similarity transfer, design problems require dynamic transfer (Schwartz, Varma, & Martin, in press) because design involves interaction, iteration, and coordination of new learning. The participants were two cohorts of senior student teams in the capstone design class at a large public university. A 2-month design project is our in-situ intervention. Cohort 1 teams designed digital stethoscopes whereas Cohort 2 teams selected biomedical devices to redesign. A design test was completed before and after the project and coded based on our three facets of expertise, though transfer presented a challenge. Voice of the Customer (VOC), which involves multiple perspective taking, was leveraged as a proxy for transfer.

Results

A two-group MANOVA reported a significant multivariate effect, $F(3, 41) = 7.59$, p <0 .00, power = 0.98. Further univariate analysis revealed significant effects for conceptual knowledge, $F(1, 43) = 4.58$, $p = 0.02$, power = 0.68, and transfer, $F(1, 43) = 4.56$, $p < .001$, power = 0.96, but not for factual knowledge, $F(1, 43) = 0.00$, $p = 0.96$. The canonical function that maximally separated the cohorts, using standardized scores is Model 3, $E = -0.21F + 0.58C + 0.90T$. The $F < C < T$ ordinality is maintained. Because Cohort 2 teams selected their own devices, they were likelier to incorporate the VOC. This experiment demonstrates that the model is generalizable to a process-dominated domain.

Relating to Adaptive Expertise

Adaptive Expertise (AE) is the ability to adapt to novel problems (Hatano & Inagaki, 1986) and involves transfer to new situations (Hatano & Inagaki, 1986). Schwartz, Bransford, and Sears (2005) proposed AE dimensions of innovation and efficiency. To examine the fidelity of VOC as a proxy for transfer we relate to efficiency to factual and conceptual knowledge and innovation to transfer. We examine long-term variation in AE as scored by experts, controlling for short-term gains in factual knowledge, conceptual knowledge, and transfer.

Results

A group level MANOVA reported a significant multivariate effect, $F(2, 39) = 3.70$, $p = 0.03$, power = 0.65. Cohort 2 teams were rated higher on innovation without compromising their efficiency scores. The effect on innovation was significant, $F(1, 40) = 5.92$, $p = 0.02$, power = 0.66. The effect on efficiency was not, $F(1, 40) = .04$, $p = 0.84$. Cohort 2 was found to have developed more on innovation, meaning that our proxy approximated transfer Cohort 2 had more opportunities to engage in procedural learning (Goel, 2000). This has instructional implications.

Conclusion

Although there seems to be consensus in the literature on facets of expertise (Bransford et al., 2000), their relative importance has not been studied. Our analysis provides confirmatory support for an earlier theoretical hypothesis: Facts are less important than concepts, and concepts are less important than the ability to transfer in being able to distinguish expertise. We now have a sense of the ordinal relationships of these components to the development of expertise in at least one domain, bioengineering. The weights across experiments were not identical, which may indicate that learning in a process-dominant context may be different than when learning content is emphasized. Future research should address generalizability and consider other views of transfer.

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