Hierarchically Ordered Instructional Activities for the Development of Clinically Relevant Competencies: A Sequential Path Model

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A potential benefit in medical education is the use of hierarchially ordered instruction (Bloom's taxonomy of educational objectives) to progressively develop the intellectual capabilities leading to clinically relevant competencies in medical students. In this study, faculty observations indicated significant improvements in the students clinically relevant competencies compared to students trained without hierarchially ordered instructional methods. Student responses demonstrated that the sequential ordering of instructional activities significanlty contributed to the development of their evolving clincial competencies ($R^2_M = .62$, $p < .05$).

Throughout the 20th century, developmental psychologists observed that human intellectual capabilities and knowledge-based competencies matured in a roughly developmentally progressive manner. That is, in a series of hierarchically ordered stages representing a logical progression from simple to more complex capabilities and competencies. Bloom (1956) codified these observations by defining six hierarchically ordered steps beginning with information/knowledge acquisition, followed by comprehension, then application, analysis, synthesis, and finally evaluation oriented capabilities and competencies. He further posited that hierarchically ordered instruction (i.e., instruction designed to sequentially develop these six capabilities/competencies – one step at a time) represented an effective instructional strategy (Bloom, 1956, p. 78-88).

While there is reason to believe that medical students could benefit from hierarchially ordered instructional activities, there is little if any evidence of its utility in the medical education setting. Our research therefore investigated the use of hierarchically ordered instruction as a means of improving the clinically relevant competencies of sophomore medical students in the area of respiratory medicine. The clinically relevant competencies of particular interest in this study involved two core knowledge-based competencies: diagnostic ability and ability to use basic and clinical science concepts and principles to explain clinical phenonema. Our approach involved faculty observations of the performance of students trained with hierarchically ordered instructional activities compared with the performance of students trained under our traditional curriculum. Our approach requires a brief review of the traditional instruction and assessment methods in use throughout our year two curriculum at the time this research was conducted and a review of the specific instruction and assessment methods used in our sequential ordered instructional program.

Traditional Instruction and Assessment Methods

No formalized learning sciences principles, methods, or framework served as a guideline or blueprint for the construction of our traditional Year Two coursework. A review of scheduled curricular activities revealed that approximately 85 - 90% of all faculty/student interactions occurred in the form of traditional lecture based instruction, that is, information acquisition-oriented instruction in a large classroom environment. Student and faculty surveys demonstrated that approximately 10% - 15% of scheduled class time involved the use of case vignettes or approximately 1 – 2 case vignettes per contact hour. While case vignettes represented a small component of instructional activities, there did not appear to be any evidence that they were formally used to develop higher level intellectual capabilities (such as comprehension and application capabilities). There was no evidence that a formal hierarchical ordering of instruction was in place, that is, passive information acquisition oriented instruction preceding case vignette based comprehension activities, followed in turn by case vignette based application activities.

Following a review of our Year Two examinations, approximately 85% of the test items appeared to be first-order, multiple choice, recognition oriented items noted by Bloom (1956) as tests of the recall of acquired information. Approximately 10% - 15% of test items were in the form of more clinically relevant second-order questions (case vignette based). A second-order question was defined as students being presented with a case vignette followed by a basic or clinical science oriented question. Students used the signs and symptoms in the vignette to draw an inference regarding the disease represented by the vignette. Having drawn a diagnostic inference, the student then used their diagnoses as the basis for answering the basic or clinical science oriented question associated with the test item vignette. Thus, a second-order case vignette test item provided students an opportunity to demonstrate both their diagnostic competency and evolving ability to apply various basic and clinical science concepts most relevant to the disease represented by the vignette.

Sequential Ordered Instruction Method

A sequential, hierarchically ordered instructional method was developed for use in a respiratory medicine course in year two (RM2). The new approach replaced all traditional passive in-class instructional methods with active, hierarchically ordered instructional activities. The RM2 course contained eight problem specific instructional modules as the basis for reorganizing the content of the course. The eight problems covered were adult dyspnea, pediatric dyspnea, hemoptysis, cough, epistaxis, rhinitis, otalgia and sore throat. Each problem specific instructional module began with information acquisition (pre-classroom reading assignments oriented to the problem at hand and its disease differentials), followed by in-class, comprehension oriented instructional activities, followed by in-classroom, application instructional activities. The RM2 course used reality oriented case-vignettes as the basis for all comprehension and application oriented instructional activities and used audience response technologies to support student engagement and teacher/student interaction in all classroom based comprehension and application oriented instructional activities. The RM2 course also used a web-based artificial intelligence tool (called KBIT) to provide problem-specific, hierarchically ordered differential diagnostic instruction to students. The number of case vignettes used in both the classroom and via computer-based training was sufficient to develop and assess the attainment of a rudimentary level of competence in diagnosing the disease differentials for each of the eight core respiratory problems as well as explain the basic and clinical science concepts underlying each problem and its disease etiologies.

RM2 scheduled coursework was allocated as follows. Thirty percent (30%) was devoted to information acquisition in the form of student self study of faculty defined reading assignments and learning objectives to guide them in their self study efforts. Sixty percent (60%) was devoted to a blend of comprehension and application-oriented instructional activities for each of the eight problem-specific modules. In developing student comprehension of key concepts and principles, faculty were asked to use the 5–6 case vignettes (per hour) to model how they themselves might use their diagnostic and explanatory knowledge in each case. Faculty were also encouraged to engage students in rudimentary attempts to apply their evolving intellectual processes and knowledge base to the diagnosis and explanation of case-related issues. Ten percent (10%) was devoted purely to Problem-Specific Knowledge Base Application Sessions (PSKBAS). These PSKBAS activities were held at the end of the course.

Method and Procedures

Participants

In-class observations by nine senior faculty (n = 9) served as the basis for assessing the students' evolving diagnostic, explanatory, and overall clinical competencies. These observations occurred in the eight PSKBAS which were held at the end of RM2 and conducted in a large classroom setting. A total of eight PSKBAS sessions occurred with each session covering one of the eight previously noted respiratory problems. The format for each PSKBAS involved the use of approximately 20 case-based vignettes per hour as stems for questions designed to elicit the students' ability to correctly diagnose each case vignette and explain the pathologic, pathophysiologic, physiologic, biochemical, or pharmacologic issues associated with particular aspects of each case vignette (second order test items). Up to four faculty members, representing various disciplines such as internal medicine, pediatrics, surgery, pathology, biochemistry, physiology, or pharmacology participated in each of the eight PSKBAS.

PSKBAS focusing upon adult dyspnea, pediatric dyspnea, hemoptysis and cough involved two hours of second-order case-vignette based questions. The remaining four problems (epistaxis, rhinitis, otalgia and sore throat) involved one hour of these second-order case vignette presentations. During these 12 hours of PSKBAS, over 200 hundred case vignettes with clinically related questions were presented to the students. Faculty observed the answers students gave for each case vignette via audience response technologies that collected and projected in real time the summarized reports of their responses on a large projection screen. Shortly following the completion of the RM2 course, a ten item questionnaire was presented to the nine senior faculty members primarily responsible for constructing and directing all of the RM2 course comprehension and application sessions as well as the eight PSKBAS.

The faculty observations served as a means of directly evaluating the evolving clinical capabilities and competencies of the RM2 trained students, and indirectly, the effectiveness of learning sciences framework used to design RM2 coursework. Three faculty questionnaire items were specifically designed to gather faculty impressions of student performance in regards to their overall clinical capabilities, diagnostic capabilities, and explanatory capabilities (ability to use basic and clinical science concepts and principles to explain various clinical phenomena). These three questions all had the same answer set which enabled faculty to compare the clinical capabilities of students in the RM2 course to students in our traditional instructional course. A chi-square analysis was applied to these faculty based observations and impressions.

One hundred and nine students (n = 109) out of 121 students completed a 55 item post RM2 course questionnaire. Students responded to Likert scaled items consisting of five possible responses (strongly agree, agree, neutral, disagree, strongly disagree). The first seventeen items in Table 1 were placed in sequential ordered sets. The eighteenth item was used as the dependent variable. The item sets and dependent variable were analyzed in a sequential path model.

Research Questions

Our research investigation into the development of clinically relevant competencies resulted in two research questions. Will clinical faculty observations demonstrate that the performance of RM2 trained students exceeded students trained previously via our traditional curriculum? This research question involved three areas of inquiry:

a) Overall level of clinical competence achieved
b) Diagnostic capabilities
c) Level of explanatory capabilities achieved (the ability to use basic and clinical sciences concepts and principles to explain clinical phenomena).

Our second research question attempted to determine if the development of clinically relevant diagnostic competencies begins with information acquisition, followed by comprehension based capabilities, followed by an ability to successfully apply their evolving knowledge base. Will student responses provide evidence of a sequential ordered instructional change in clinical competencies?

Results

For the nine (9) clinical faculty responses, a 3 X 2 chi-square analysis was performed for all three questions posed to faculty. For *level of clinical competence achieved*, 78% of faculty reported that the RM2 trained students overall level of clinical competence exceeded expectations, which was statistically significant ($\chi^2 = 8.686$, $df = 2$, $p = 0.013$). For *diagnostic capabilities*, 67% of faculty reported that the RM2 students diagnostic capabilities exceeded expectations, which was statistically significant ($\chi^2 = 5.992$, $df = 2$, $p = 0.050$). For *level of explanatory capabilities achieved*, 75% of responding faculty reported that the ability of RM2 students to explain phenomena via use of constructs from basic and clinical sciences exceeded expectations, which was statistically significant ($\chi^2 = 7.014$, $df = 2$, $p = 0.030$). An effect size was computed to measure the degree of departure from the null hypothesis in standard units. The effect size (r) = 0.257 and Cohen's d = 0.532 (unbiased), which indicated a medium effect size (Schumacker & Akers, 2001).

For the one hundred nine student responses (n = 109) to the questionnaire items in Table 1, there were 16 missing data points out of 2,180 (109 subjects x 18 variables) representing .007 percent missing data. Missing values were replaced with a 0 (zero) so that the summative scores for the independent variables would not be influenced by mean substitution or replacement by a raw score scale value of 3 (neutral) giving more importance to a neutral item response.

Three sequential ordered independent variables were then created by summing the respective questionnaire items. Student questionnaire items 1, 2, 3, 4, 5, 6, 7, 8 were summed to represent information acquisition oriented instructional activities (Acquisition); items 9, 10, 11, 12 were summed to represent comprehension oriented instructional activities (Comprehension); and items 13, 14, 15, 16, 17

Table 1. Sequential Ordered Sets of Questionnaire Items

Course Component	Questionnaire Items
Information Acquisition	#1: The printed objectives for Pathology's respiratory and ENT reading assignments were sufficiently detailed to help me focus on the most important concepts. #2: The printed objectives set forward for Pathology's respiratory and ENT chapters enhanced my performance on examinations covering these chapters. #3: I understood most of the concepts contained within Nelson's textbook on my own with little need for clarification from an instructor. #4: The printed objectives for Pediatric's respiratory and ENT reading assignments were sufficiently detailed to help me focus on the most important concepts. #5: The printed objectives set forward for Pediatric's chapters enhanced my performance on examinations covering these chapters. #6: I understood most of the concepts contained within Internal Medicine's textbook on my own with little need for classroom sessions. #7: The printed objectives for Internal Medicine's respiratory reading assignments were sufficiently detailed to help me focus on the most important concepts. #8: The printed objectives set forward for Internal Medicine's reading assignments enhanced my performance on examinations covering these chapters.
Comprehension	#9: Interactive class sessions enhanced my understanding of the self study materials. #10: Interactive sessions following, and keyed to prior self study of a required reading assignments) should be adopted by other System Two course faculty. #11: KBIT's WEB-based 'training' cases (cases that did not require a diagnosis) helped me better understand the variety of ways patients with a given disease could present in the clinical arena. #12: The type of knowledge placed within an 'explanatory' knowledge base is related to but organized in a different format from 'diagnostic' knowledge.
Application	#13: Following a wrong diagnosis, KBIT's case-specific 'feedback' enhanced my understanding of how signs and symptoms could have been better used to correctly diagnose the case. #14: Spending an hour or more focusing on a specific clinical problem (during application sessions) improved my understanding of how to initiate my approach to cases presenting with that particular clinical problem. #15: Compared with traditional lectures, the application sessions provided a greater opportunity for me to integrate textbook and lecture derived knowledge about clinical problems and their disease differentials #16: The application sessions enhanced my evolving patient care management capabilities. #17: Application session cases and questions engaged me and challenged me in ways different than traditional course examinations.
Dependent Variable	#18: My overall level of clinical competence (i.e., diagnostic capabilities, clinical skills, treatment skills, patient care management skills) improved in Respiratory Medicine Two (RM2).

were summed to represent application oriented instructional activities (Application). These three sequential ordered variables were used to test the sequential relationship developed for the three core instructional methods used in RM2 (Acquisition, Comprehension, Application) as related to the dependent outcome variable (improved clinical competencies, item 18).

Table 2 indicates the variable scale statistics including Cronbach internal consistency reliability coefficients for the three independent variables.

Table 3 indicates the correlation amongst the variables in the path model. The correlation between Acquisition and Application was the only non-significant correlation coefficient. In a manner consistent with Bloom's taxonomy, the students' sense of their improved clinical competencies (Y) indicated increased correlation values across the sequential ordered variables (r = 0.176 to 0.388 to 0.547).

Table 2. Variable Descriptive Statistics (N = 109)

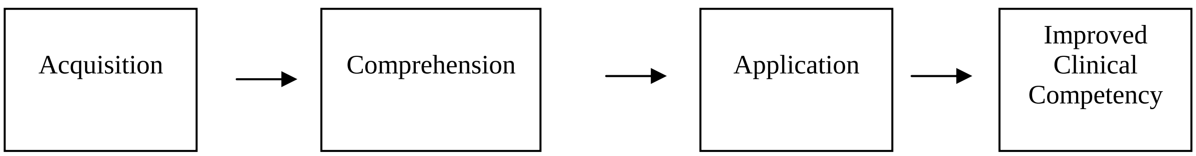
Variable	Items	Mean	SD	Reliability
Acquisition	8	21.06	5.14	.786
Comprehension	4	8.62	2.94	.606
Application	5	12.61	4.770	.839
Y	1	2.64	1.03	n/a

Table 3. Correlation Matrix (N = 109)

Variable	Y	Acquisition	Comprehension	Application
Y	1.000			
Acquisition	0.176*	1.000		
Comprehension	0.388**	0.430**	1.000	
Application	0.547**	0.075	0.568**	1.000

* $p < 0.05$, df = 108 (one-tail test); ** $p < 0.01$, df = 108 (one-tail test)

A path model analysis using structural equation modeling software (LISREL) statistically tested the research question: Will student responses provide evidence of improvements in clinical competencies due to sequentially ordered instruction? The path model was diagrammed as:



The correlation matrix is in Table 3. The sequential ordered variables yielded statistically significant path coefficients and R-squared values. The path model chi-square value was non-significant at the $p < .01$ level of significance indicating that the data fit the hypothesized theoretical path model ($\chi^2 = 8.79$, $df = 3$, $p = 0.03$). The overall R^2 value for this path model, which included direct and indirect effects, was $R^2_m = 0.615$. Findings therefore indicated that 62 percent of the variation in Y (improved clinical competencies) was explained by the sequential nature of the independent variables direct and indirect effects.

Conclusions

The curricular reform initiative represented in this study was research designed to improve the clinical capabilities and competencies of medical students. The authors believed that a learning sciences framework utilizing hierarchically ordered instructional sequencing (information acquisition, followed by comprehension, followed by application activities) could improve the clinically relevant competencies of sophomore medical students. Faculty observations provided evidence of performance improvements in the students' overall clinical capabilities and more specifically in their diagnostic and explanatory capabilties. Student feedback also validated the underlying learning sciences framework used in the design of the RM2 course and provided a cognitively based explanation as to why the students overall clinical competencies improved.

The path analysis results supported the research question, that is, intellectual development (intellectual processes and knowledge based capabilities) evolved in a logical progression as indicated by a statistically significant sequential ordering of the independent variables: Acquisition, Comprehension, and Application. The path analysis results therefore suggest that hierarchically ordered instruction represents useful means of supporting the evolving nature of the intellectual processes and knowledge based capabilities of medical students.

Efforts intended to champion curricular reform initiatives require a well planned, multi-faceted approach to evaluating the outcomes of the proposed instructional interventions (Hardin, Grant, Buckley, & Hart, 1999; Wilkes & Bligh, 1999; Norman, Eva, & Schmidt, 2005; Mamede, Schmidt, & Norman, 2006). Without such an approach, it is unlikely that curricular innovators will be able to provide evidence sufficient to argue that their particular instructional interventions merit further consideration, refinement and perhaps emulation. The results of this study provided evidence that a larger scale implementation of our sequential ordered instruction could yield positive performance improvements throughout coursework representing the entire second year of the curriculum. A recent investigation involving the use of hierarchically ordered instructional sequencing (and other learning sciences principles) across our year two curriculum (called an Application-Oriented Curriculum) has provided evidence of significant improvement of students on national Licensing Board examinations (Papa et al., in review).

References

Bloom B. S. (1956). *Taxonomy of Educational Objectives: The classification of educational goals. Handbook I: Cognitive Domain*. New York, NY. David McKay Company, Inc.

Norman G R., Eva K.W., & Schmidt H.G. (2005). Implications of psychology-type theories for full curricular interventions. *Medical Education*, *39,* 247-249.

Mamede, S., Schmidt H.G., & Norman G.R. (2006). Innovations in Problem- based Learning: What can we learn from recent studies? *Advances in Health Sciences Education*, *11*, 403-422.

Hardin R.M., Grant J., Buckley G., & Hart I.R. (1999). BEME Guide No 1: Best Evidence Medical Education. *Medical Teacher*, *21* (*6*), 553-662.

Papa, F.J., Oglesby, M.W., Dubin, B.D., Gwirtz, P.A., Martin, M.W. & Putthoff, S.L. (in review). An Application-Oriented Curriculum: Rationale, Learning Sciences Framework and Outcomes. *Medical Education*.

Wilkes M. & Bligh J. (1999). Evaluating educational interventions. *British Medical Journal*, *318*,1269-1272.

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