

FACULTY CONCEPTIONS ABOUT THE TEACHING AND LEARNING OF
PROBLEM SOLVING IN INTRODUCTORY CALCULUS-BASED PHYSICS

A THESIS

SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA

BY

CHARLES ROY HENDERSON

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

PATRICIA HELLER, ADVISOR

JUNE, 2002

© CHARLES ROY HENDERSON, 2002

UNIVERSITY OF MINNESOTA

This is to certify that I have examined this copy of a doctoral thesis by

CHARLES ROY HENDERSON

And have found that it is complete and satisfactory in all respects,
and that any and all revisions required by the final
examining committee have been made.

PATRICIA HELLER

Advisor

Signature

Date

GRADUATE SCHOOL

DEDICATION

To my wife, Jill Terwilliger, for her love and support throughout this long process.

ACKNOWLEDGEMENTS

I would like to thank the many people whose time, effort, and support were greatly appreciated in the completion of this dissertation.

I thank my advisor, Dr. Patricia Heller, for her guidance and support during this project. She has taught me what it means to conduct research.

I thank Dr. Edit Yerushalmi for her help and support on this project and her keen insight into the teaching/learning process. I have learned much from our conversations.

I thank Dr. Kenneth Heller for his continual advice and encouragement. He has taught me how to give a good presentation.

I thank Dr. Frances Lawrenz for her many helpful conversations throughout this project.

I thank Vince Kuo for his work on this research project and for his editing skills.

Finally, I thank the 6 instructors who agreed to be interviewed as part of this study. Their willingness to talk with me about their views of the teaching and learning of problem solving made this study possible.

ABSTRACT

Researchers and curriculum developers have developed a wide variety of curricular materials and instructional strategies that have been shown to be effective in improving student problem solving performance. Relatively few physics faculty, however, have chosen to use them. One likely reason is that these curricular materials and instructional strategies do not align with the ways that faculty think about the teaching and learning of problem solving.

This study is the first stage of a research program to understand faculty conceptions of the teaching and learning of problem solving. Interviews with six physics faculty from a large research university were used to generate an initial explanatory model of faculty conceptions. The interview was designed around three types of concrete instructional artifacts (3 instructor solutions, 5 student solutions, 4 types of problems).

Based on an in-depth analysis of the interview transcripts, a model of faculty conceptions was developed that consists of 14 general features. The basic relationships between these 14 general features are described in a concept map that is common to all six faculty. For example, there are three distinct ways that faculty think students can learn how to solve physics problems: (1) by solving problems on their own; (2) by using feedback while/after working on problems; (3) by watching someone else solve problems or describe how to solve problems.

Concept maps are also used to describe each of the 14 general features. For some of the general features, all six faculty have similar conceptions. For example, they all classify their students in terms of intelligence/natural ability and learning characteristics (e.g. motivation, study habits, etc.) and use these characteristics to explain why some students succeed and some students fail. For other general features, there is more than one distinct conception. For example, the model shows three different ways that these faculty conceive of the problem solving process: (1) three think of it as a linear decision-making process; (2) two think of it as a process of exploration and trial and error; and (3) one thinks of it as an art form that is different for each problem.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION.....	1
BACKGROUND	3
<i>Ways of learning about teachers' conceptions</i>	4
PRIOR RESEARCH INTO TEACHERS' CONCEPTIONS	4
<i>The Relationship Between Teachers' Conceptions and Their Instructional Choices.</i> .	5
<i>The Nature of Teachers' Conceptions.</i>	5
MODEL GENERATION AND TESTING	5
<i>Phenomenographic Investigations of Thinking.</i>	7
RESEARCH QUESTIONS	8
RESEARCH DESIGN AND ANALYSIS.....	9
<i>Significance of the Study</i>	9
<i>Limitations of the Study.</i>	10
THE RESEARCH TEAM.....	11
IMPORTANT TERMINOLOGY	11
OVERVIEW OF THIS DISSERTATION.....	12
CHAPTER 2: LITERATURE REVIEW.....	14
RESEARCH ON TEACHING	14
<i>Research on Teachers' Behavior</i>	15
<i>Research on Teachers' Cognitions</i>	16
<i>Teachers' Decision-Making</i>	17
Preactive thinking	18
Interactive thinking	21
Summary of Research on Teachers' Decision-Making	24
<i>Teachers' Conceptions</i>	25
<i>Teachers' General Conceptions.</i>	28
Conceptions of Teaching and Learning	28
Conceptions of Subject Matter.....	36
Conceptions of the Teaching Context	39
Teachers' Context-Specific Conceptions.....	42

Expertise In Teaching	45
Reflection.....	48
Summary of Research on Teachers’ Conceptions	50
RESEARCH ON EFFECTIVE TEACHING OF PROBLEM SOLVING	51
<i>Differences Between Expert and Novice Problem Solvers</i>	51
Differences in Knowledge	51
Differences in Approaches to Problem Solving.....	52
<i>Strategies Designed to Improve Student Problem Solving</i>	53
Problem Solving Framework	56
“Real” Problems.....	57
Scaffolded Practice	57
Concept Maps	58
Summary of Effective Teaching of Problem Solving	58
CHAPTER 3: METHODS	60
METHODOLOGY	60
<i>Goals of the study</i>	60
<i>Phenomenography</i>	62
PROCEDURE	63
DEVELOPMENT OF THE INTERVIEW TOOL	64
<i>Basing The Interview Tool on One Physics Problem</i>	64
<i>Developing Interview Artifacts</i>	65
Instructor Solutions	66
Student Solutions	66
Problem Types	67
<i>Pilot Testing of the Interview Tool</i>	67
<i>The Final Interview Tool</i>	69
SCHEDULING AND CONDUCTING THE INTERVIEWS	69
<i>Teaching context of interview participants</i>	71
Lecture	71
Discussion Sessions	72
Laboratories	72

ANALYSIS OF THE INTERVIEW DATA	73
<i>Transcription</i>	75
<i>Experimenting With Analysis Methods</i>	75
Using Units of Action	76
Argument Structure Analysis	76
Using Teaching Episodes	77
<i>Converging on the Final Analysis Method</i>	78
Unit of Analysis	78
Breaking The Transcript Into Statements	80
Goal of Analysis	82
<i>Representing Data Using Concept Maps</i>	82
Concept Maps	83
Developing the Concept Maps	84
Procedure	85
Verification of Individual Concept Maps	86
Developing Combined Concept Maps	87
Categories of Knowledge/Skill Related to Problem Solving	87
Identifying Qualitatively Different Ways of Viewing each General Feature	88
Viability	88
<i>An Example to Clarify the Analysis Procedure</i>	91
Making Statements	91
Creating an Individual Concept Map	91
Combining Concept Maps	96
SUMMARY	100
CHAPTER 4: RESULTS AND CONCLUSIONS	101
CONCEPT MAPS	101
<i>Concept Map Symbols</i>	102
MAIN MAP	106
<i>Who Can Learn?</i>	106
<i>Student Engagement in Learning Activities</i>	106
<i>Instructor Management</i>	107

FEATURE MAPS	110
Map 1: Some College Students	112
Map 2: Solve Physics Problems.....	115
Map 3: Students' Current State	118
<i>Learning Activities Cluster</i>	123
Map 4: Student Engagement in Learning Activities of Working (Path A).....	123
Map 5: Student Engagement in Learning Activities of Using Feedback (Path B)	126
Map 6: Student Engagement in Learning Activities of Looking/Listening (Path C)	
.....	129
<i>Resources Cluster</i>	132
Map 7: Resource of Appropriate Problems	132
Map 9: Resource of Appropriate Example Solutions	139
Map 8: Resource of Individualized Responses	146
<i>Management Cluster</i>	152
Map 11: Management of Students' Engagement in Learning Activities of Working	
(Path A).....	152
Map 12: Management of Students' Engagement in Learning Activities of Using	
Feedback (Path B)	155
Map 13: Management of Students' Engagement in Learning Activities of	
Looking/Listening (Path C)	161
Map 10: Appropriate Knowledge	164
Map 14: Reflection on Teaching.....	168
SUMMARY.....	171
CHAPTER 5: IMPLICATIONS	177
SUMMARY OF STUDY.....	177
THEORETICAL IMPLICATIONS.....	178
METHODOLOGICAL IMPLICATIONS	179
RELATION TO PRIOR RESEARCH	179
Some College Students (Map 1)	180
Solve Physics Problems (Map 2)	181
Students' Current State (Map 3)	181
Learning Activities Cluster (Maps 4-6)	182
Management and Resources Clusters (Maps 7-9 and 11-13)	184

Appropriate Knowledge (Map 10)	187
Reflection on Teaching (Map 14)	188
THE INSTRUCTIONAL PARADOX	189
<i>Evidence for the Instructional Paradox</i>	190
The Role of Prior Experience in Problem Solving	190
The Role of PERFORMANCE MONITORING in Problem Solving	191
<i>Possible Reasons for the Instructional Paradox</i>	191
Knowledge About the Initial State of the Student	192
Knowledge About the Desired Learner Outcomes	192
Knowledge About How a Student Can Move From Their Initial State to Reach the Desired Outcome	193
Knowledge of Teaching Strategies	194
SPECIFIC UNANSWERED QUESTIONS FOR FUTURE STUDIES	196
Do Instructors Think That They Teach Motivated Students?	196
Do Instructors Use the Same Three Perspectives When Thinking About All of Their Management Decisions?	196
Is the Resource of Individualized Responses More Than One Resource?	197
What is the Relationship Between Beliefs About Problem Solving and Beliefs About the Teaching and Learning of Problem Solving?	197
What is the Role of Each of the Learning Activities?	198
REFERENCES	200
APPENDICES	211
A INTERVIEW ARTIFACTS: INSTRUCTOR SOLUTIONS	211
B INTERVIEW ARTIFACTS: STUDENT SOLUTIONS	215
C INTERVIEW ARTIFACTS: PROBLEMS	221
D INTERVIEW PROTOCOL	226
E PACKED MAILED TO INTERVIEWEE PRIOR TO INTERVIEW	233
<i>Cover Letter</i>	233
<i>Homework Problem</i>	233
<i>Background Questionnaire</i>	233
F CONSENT FORM	240
G NOTE CARDS AND CATEGORIZATION FOR EACH INSTRUCTOR	243

LIST OF FIGURES

Figure 1-1: Cyclical process of generation and modification in the development of explanatory models. (Clement, 2000, p. 554)	6
Figure 2-1: Model of teachers decision making during interactive teaching (Shavelson & Stern, 1981)	22
Figure 2-2: Framework for Understanding Research on Teaching	26
Figure 3-1: Problem upon which interview artifacts were based (Homework Problem) .	65
Figure 3-2: System diagram of the learning environment that was used to develop categories to guide the construction of statements from the interview transcript.	79
Figure 3-3: Composite concept map that describes instructors' conceptions of "Some College Students".	84
Figure 3-4: Procedure for Developing Feature Maps	85
Figure 3-5: A piece of the interview transcript from interview situation IV, question #7. CH is interviewing RU6.	93
Figure 3-6: RU6 Individual Map 1 (Some College Students)	96
Figure 3-7: RU3 Individual Map 1 (Some College Students)	98
Figure 3-8: RU4 Individual Map 1 (Some College Students)	98
Figure 3-9: Composite Map 1 (Some College Students)	99
Figure 4-3: Map 1 - Some College Students.....	114
Figure 4-4: Map 2 - Solve Physics Problems.....	117
Figure 4-5: Map 3 (short) - Students' Current State.....	120
Figure 4-6: Map 3 (part 1) - Students' Current State	121
Figure 4-7: Map 3 (part 2) - Students' Current State	122
Figure 4-8: Map 4 – Student Engagement of Learning Activities of Working (Path A)	125
Figure 4-9: Map 5 – Student Engagement of Learning Activities of Using Feedback (Path B)	128
Figure 4-10: Map 6 – Student Engagement of Learning Activities of Looking/Listening (Path C)	131
Figure 4-11: Map 7 (short) – Resource of Appropriate Problems	136
Figure 4-12: Map 7 (part 1) – Resource of Appropriate Problems	137
Figure 4-13: Map 7 (part 2) – Resource of Appropriate Problems	138
Figure 4-14: Map 9 (short) – Resource of Appropriate Example Solutions	143
Figure 4-15: Map 9 (part 1) – Resource of Appropriate Example Solutions	144

Figure 4-16: Map 9 (part 2) – Resource of Appropriate Example Solutions	145
Figure 4-17: Map 8 (short) – Resource of Individualized Responses	149
Figure 4-18: Map 8 (part 1) – Resource of Individualized Responses	150
Figure 4-19: Map 8 (part 2) – Resource of Individualized Responses	151
Figure 4-20: Map 11 – Management of Students’ Engagement in Learning Activities of Working (Path A).....	154
Figure 4-21: Map 12 (short) – Management of Students’ Engagement in Learning Activities of Using Feedback (Path B).....	158
Figure 4-22: Map 12 (part 1) – Management of Students’ Engagement in Learning Activities of Using Feedback (Path B).....	159
Figure 4-23: Map 12 (part 2) – Management of Students’ Engagement in Learning Activities of Using Feedback (Path B).....	160
Figure 4-24: Map 13 – Management of Students’ Engagement in Learning Activities of Looking/Listening (Path C).....	163
Figure 4-25: Map 10 – Appropriate Knowledge	167
Figure 4-26: Map 14 – Reflection on Teaching.....	170

LIST OF TABLES

Table 3-1: Six interview participants from the University of Minnesota	70
Table 3-2: Four levels of knowledge compared for a physical science study and the current study. This table is based on a table created by Clement (2000, p. 550).	74
Table 3-3: Statements made from a piece of the interview transcript from RU6.	94
Table 4-1: Summary of instructors' conceptions of Some College Students, Solve Physics Problems, and Students' Current State.	172
Table 4-2: Summary of instructors' conceptions of what students can/should do to learn how to solve physics problems.	173
Table 4-3: Summary of instructors' conceptions of resources that can be provided to help students learn.	174
Table 4-4: Summary of instructors' conceptions of management of student learning activities.	175
Table 4-5: Summary of instructors' conceptions of Appropriate Knowledge and Reflection on Teaching.	176