STRATEGIES FOR PROMOTING REAL-WORLD CONNECTIONS IN PROBLEM SOLVING FOR INTRODUCTORY PHYSICS

by

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ABSTRACT

It is well known that students’ beliefs about the nature of knowledge and learning in physics affect their motivation and learning in this subject. In this thesis I examine a course transformation that presented the entire course in terms of real-world circumstances and problems which was intended to promote students’ perception of the relevance of physics to the real world and to enable them to develop problem-solving skills for addressing complex real-world problems. By examining course-wide surveys I demonstrate that the intended improvement in students’ perception of the relevance of physics did not occur, suggesting that teaching physics in a real-world context is not, in itself, sufficient for improving students’ belief in the relevance of physics. Two interview studies reveal some of the features that students report are important in their perception of the relevance of physics to the real world. I use the theoretical framework of epistemological framing and resources to study students’ response to complex real-world problems that were intended to promote students’ use of real-world knowledge and enable development of expert-like problem-solving skills. I argue that students’ use of real-world knowledge within a physics context are opportunities for them to develop a more favorable attitude towards physics in general and develop a coding scheme for identifying these instances. This study demonstrates that students’ use of their real-world knowledge in physics is highly correlated with their framing of their activity as conceptual (rather than procedural) discussion. In addition, I demonstrate that the course’s structured problem solving method is not effective at promoting conceptual discussion at appropriate times during the problem-solving process.
PREFACE

This research was conducted under approval from UBC’s Behavioral Research Ethics Board under study IDs H07-01702, H08-01676, and H09-02793.
# Table of Contents

Abstract ............................................................................................................................... ii
Preface ................................................................................................................................. iii
Table of Contents ................................................................................................................ iv
List of Tables ....................................................................................................................... xi
List of Figures ...................................................................................................................... xv
Acknowledgements ........................................................................................................... xvii
Dedication ............................................................................................................................ xviii

1 Introduction ...................................................................................................................... 1
  1.1 Motivation: Useful Education ..................................................................................... 1
  1.2 Changes to Physics 100 .............................................................................................. 2
    1.2.1 Integrating Physics and Real-World Knowledge ............................................... 2
    1.2.2 Beliefs About Relevance of Physics .................................................................. 3
    1.2.3 Problem Solving ................................................................................................. 4
  1.3 Research Approach and Research Questions ............................................................. 5
    1.3.1 Research on Beliefs About Relevance Of Physics .............................................. 5
    1.3.2 Research on Integrating Physics and Real-World Knowledge ......................... 6
    1.3.3 Research on Conceptual Discussion During Problem Solving ....................... 6
  1.4 Dissertation Overview ............................................................................................... 7
    1.4.1 Study of Changes in Students' Beliefs ................................................................. 8
    1.4.2 Exploratory Post-Course Interviews .................................................................. 9
    1.4.3 Structured Real-World Connections Interviews ............................................... 10
    1.4.4 Epistemological Framing and Real-World Connections in Structured Group Problem-Solving ................................................................. 10

2 Development of Physics 100 .......................................................................................... 13
  2.1 Background of Physics 100 ....................................................................................... 13
  2.2 Motivation for Changes ............................................................................................. 13
    2.2.1 Students’ Understanding of Societally Relevant Issues .................................. 14
    2.2.2 Retention ............................................................................................................ 14
    2.2.3 Perception of Relevance of Physics ................................................................... 15
    2.2.4 Decline in CLASS Survey Scores ..................................................................... 15
    2.2.5 Real-World Problem-Solving Skills .................................................................. 16
  2.3 Goals of Changes ....................................................................................................... 16
2.4 Changes to Physics 100 ........................................................................................................ 17
  2.4.1 Everyday Context ........................................................................................................... 17
  2.4.2 Course Content .............................................................................................................. 18
    2.4.2.1 Thermal Physics and Climate Change ................................................................. 19
    2.4.2.2 Air Resistance and Energy in Transportation ..................................................... 20
    2.4.2.3 Chemical and Metabolic Energy ......................................................................... 21
    2.4.2.4 Power in Circuits ............................................................................................... 21
    2.4.2.5 Eliminated Topics ............................................................................................... 21
  2.4.3 Problem-Solving Skills ................................................................................................. 22
    2.4.3.1 Modeling and Assumptions ................................................................................ 23
  2.4.4 Structured Problem-Solving ....................................................................................... 24
    2.4.4.1 Step 1: Interpret the Problem ............................................................................ 25
    2.4.4.2 Step 2: Identify Relevant Physics ...................................................................... 26
    2.4.4.3 Step 3 & 4: Create a Physics Model ................................................................. 26
    2.4.4.4 Step 5: Solve the Problem ................................................................................ 28
    2.4.4.5 Step 6: Error-Checking and Sensemaking ......................................................... 28
    2.4.4.6 Complete Physics 100 Problem Solving Strategy ........................................... 29
    2.4.4.7 On the Lack of a Planning Step ....................................................................... 31
    2.4.4.8 Scoring ............................................................................................................. 32
  2.4.5 Changes to Recitations ................................................................................................. 34
    2.4.5.1 Context-Rich Recitations .................................................................................. 35
    2.4.5.2 Group Structure and Roles ............................................................................... 36
    2.4.5.3 Workshops for Introducing Problem-Solving Skills ...................................... 37
    2.4.5.4 Everyday Context ............................................................................................ 39
    2.4.5.5 Motivation for Calculation .............................................................................. 40
    2.4.5.6 Two Versions of Each Tutorial ....................................................................... 40
    2.4.5.7 Solutions as Worked Examples ...................................................................... 42
  2.4.6 Changes to Lecture ....................................................................................................... 43
  2.4.7 Group Research Project ............................................................................................... 44

3 Study of Changes in Students’ Beliefs About Physics ......................................................... 45
  3.1 Goal and Research Question ........................................................................................... 45
  3.2 Methodology .................................................................................................................. 45
  3.3 CLASS Survey Results .................................................................................................. 47
3.4 Analysis of Pre-Course Scores ................................................. 49
3.5 Analysis of Lack of Change in 2007 ........................................... 51
  3.5.1 Differences in Population due to Recruitment Method ............ 52
  3.5.2 Faculty Changes ............................................................. 52
3.6 Analysis of Decline in 2009 .................................................... 54
  3.6.1 Instructor Changes .......................................................... 54
  3.6.2 Student Demographics .................................................... 56
  3.6.3 Timing differences .......................................................... 56
3.7 Summary .............................................................................. 58
4 Exploratory Post-Course Interviews ............................................ 59
  4.1 Goal and Research Questions ................................................. 59
  4.2 Selection of Participants ...................................................... 60
  4.3 Interview Protocol ................................................................ 60
  4.4 A Methodological Comment .................................................. 63
  4.5 Interview Results ............................................................... 64
    4.5.1 Diverse Interpretation of “Reasoning Skills Used to Understand Physics” ..... 64
      4.5.1.1 Reasoning Skills as Problem Solving .............................. 64
      4.5.1.2 Reasoning Skills as Physics Content .............................. 66
      4.5.1.3 Reasoning Skills as Common Sense ............................... 67
      4.5.1.4 Reasoning Skills as Exam-Taking Strategies .................. 68
    4.5.2 Conceptions of Physics in the Real World .......................... 69
      4.5.2.1 Physics as Relevant Environmental Issues ..................... 69
      4.5.2.2 Physics as Relevant vs. Physics as Worth Noticing .......... 71
      4.5.2.3 Physics as Calculations ............................................. 71
    4.5.3 Factors Influencing Perception of Relevance ...................... 72
      4.5.3.1 Personal Perspective on Real-World Relevance ................ 72
      4.5.3.2 Interpretation of Realism of Tutorials ......................... 73
    4.5.4 Summary ....................................................................... 74
5 Structured Real-World Relevance Interviews ............................... 75
  5.1 Goal and Research Questions ................................................. 75
  5.2 Methodology ....................................................................... 76
    5.2.1 Interview Cohort ............................................................ 76
    5.2.2 Interview Protocol .......................................................... 77
6.3.3.1 Data ........................................................................................................... 121
6.3.3.2 Methodology ............................................................................................. 121
6.3.3.3 Results ...................................................................................................... 123
6.3.3.4 Limitations of Audio-Only Coding for Epistemological Framing .......... 125
6.3.3.5 Comments on Scherr and Hammer’s Original Coding ......................... 126
6.3.3.6 Summary .................................................................................................. 127
6.3.4 Development of Epistemological Framing Coding Scheme .................. 128
6.3.4.1 Adaptation to Cohort ............................................................................... 128
6.3.4.2 Conceptual and Procedural Discussion .................................................. 129
6.3.4.3 Differences in Worksheet Frame .............................................................. 137
6.3.4.4 Comparison of Procedural Discussion and Worksheet Frame .......... 139
6.3.4.5 Other New Frames .................................................................................. 140
6.3.4.6 Summary of Framing Coding Scheme ..................................................... 141
6.3.4.7 Example of Framing Coding ................................................................. 141
6.3.4.8 Framing Inter-Rater Reliability Testing .................................................. 146
6.3.4.9 Limitations of Coding Methodology ...................................................... 149
6.3.5 Coding Real-World Connections ............................................................... 152
6.3.5.1 Development of RWC Coding Scheme ................................................ 153
6.3.5.2 RWC Inter-Rater Reliability Testing ...................................................... 155
6.3.5.3 Summary of RWC Coding Scheme ....................................................... 156
6.3.6 Equivalence of Frames and Codes .............................................................. 164
6.4 Coding Results and Analysis ........................................................................ 164
6.4.1 Selection of Data ......................................................................................... 164
6.4.2 Correlation Between Frame and RWC ....................................................... 165
6.4.2.1 Frequency of RWC by Frame ............................................................... 165
6.4.2.2 Investigation of Positive RWC in the M Frame .................................... 167
6.4.2.3 Examination of RWC by Episode ......................................................... 170
6.4.2.4 Do the High RWC Groups Engage in More Conceptual Discussion? ... 172
6.4.2.5 Real-World Connections in the Conceptual Discussion Frame .......... 176
6.4.3 Correlation Between Prompts and Conceptual Discussion ...................... 182
6.4.4 Correlation Between Prompts and RWC ................................................... 184
6.4.4.1 RWC in the Assumptions Prompt .......................................................... 186
6.4.4.2 RWC in the Solve Prompt ..................................................................... 189
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4.4.3</td>
<td>RWC in the Sensemaking Prompt</td>
<td>192</td>
</tr>
<tr>
<td>6.4.4.4</td>
<td>Summary</td>
<td>194</td>
</tr>
<tr>
<td>6.4.5</td>
<td>Analysis of Negative RWC</td>
<td>194</td>
</tr>
<tr>
<td>6.4.5.1</td>
<td>Detail of Tutorial (4 clusters)</td>
<td>197</td>
</tr>
<tr>
<td>6.4.5.2</td>
<td>Motivation for Calculation (6 clusters)</td>
<td>198</td>
</tr>
<tr>
<td>6.4.5.3</td>
<td>Physics Vs. Common Sense (1 cluster)</td>
<td>201</td>
</tr>
<tr>
<td>6.4.5.4</td>
<td>Relevant Experience (1 cluster)</td>
<td>202</td>
</tr>
<tr>
<td>6.4.5.5</td>
<td>Interpretation of Goal (2 clusters)</td>
<td>204</td>
</tr>
<tr>
<td>6.4.5.6</td>
<td>Vaguely Negative (3 clusters)</td>
<td>204</td>
</tr>
<tr>
<td>7</td>
<td>Discussion and Conclusions</td>
<td>206</td>
</tr>
<tr>
<td>7.1</td>
<td>Research Question 1: Impact of Physics 100 Reform on Student Beliefs</td>
<td>206</td>
</tr>
<tr>
<td>7.1.1</td>
<td>Discussion</td>
<td>206</td>
</tr>
<tr>
<td>7.1.2</td>
<td>Positive Impacts of Course Transformation</td>
<td>207</td>
</tr>
<tr>
<td>7.2</td>
<td>Research Question 2: Types of Real-World Connection</td>
<td>208</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Judgment of Relevance</td>
<td>208</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Use of Real-World Resources in Physics</td>
<td>209</td>
</tr>
<tr>
<td>7.2.3</td>
<td>Discussion</td>
<td>209</td>
</tr>
<tr>
<td>7.3</td>
<td>Research Question 3: Factors Influencing Real-World Connections</td>
<td>210</td>
</tr>
<tr>
<td>7.3.1</td>
<td>Factors Affecting Perception of Relevance</td>
<td>211</td>
</tr>
<tr>
<td>7.3.1.1</td>
<td>Context</td>
<td>212</td>
</tr>
<tr>
<td>7.3.1.2</td>
<td>Consequences</td>
<td>213</td>
</tr>
<tr>
<td>7.3.1.3</td>
<td>Quantitative Reasoning</td>
<td>215</td>
</tr>
<tr>
<td>7.3.2</td>
<td>Factors Affecting Use of Real-World Knowledge</td>
<td>217</td>
</tr>
<tr>
<td>7.3.2.1</td>
<td>Epistemic Framing</td>
<td>218</td>
</tr>
<tr>
<td>7.3.2.2</td>
<td>Problem-Solving Strategy</td>
<td>219</td>
</tr>
<tr>
<td>7.3.2.3</td>
<td>Generalizing Beyond RWC</td>
<td>220</td>
</tr>
<tr>
<td>7.4</td>
<td>Research Question 4: Influence of Structured Problem-Solving Methods on Conceptual Discussion</td>
<td>221</td>
</tr>
<tr>
<td>7.5</td>
<td>Methodological Contributions</td>
<td>222</td>
</tr>
<tr>
<td>7.5.1</td>
<td>Interpretation of CLASS results</td>
<td>223</td>
</tr>
<tr>
<td>7.5.2</td>
<td>Development of Coding Scheme for Real-World Connections</td>
<td>224</td>
</tr>
<tr>
<td>7.5.3</td>
<td>Extension of Epistemological Framing Coding Scheme</td>
<td>224</td>
</tr>
<tr>
<td>7.6</td>
<td>Recommendations for Instruction</td>
<td>225</td>
</tr>
</tbody>
</table>
References .............................................................................................................................. 234
Appendix A Physics 100 Tutorial Problems................................................................. 239
Appendix B Exploratory Post-Course Interview Protocol ......................................... 344
Appendix C Structured Real-World Connections Interview Protocol ....................... 347
Appendix D Epistemological Framing Coding Rubric.................................................... 360
Appendix E Real-World Connections Coding Rubric..................................................... 366
LIST OF TABLES

Table 1: Overall dissertation research questions and sub-questions by chapter. ............... 8
Table 2: Summary of the structured problem-solving strategy used in Physics 100. These are the titles of the problem-solving steps that were used in lecture and recitation... 29
Table 3: Detail of the structured problem-solving strategy used in Physics 100. These are the prompts that were written on the recitation worksheets completed by the students. ................................................................................................................. 30
Table 4: Marking rubric used for Physics 100 recitation problems....................................... 34
Table 5: Skill and content focus for the first five Physics 100 recitations. These recitations were structured as workshops on developing students’ skills for individual steps of the overall problem-solving method. ................................................................. 39
Table 6: Criteria for personal context and real context tutorials. Each recitation problem in 2009 was developed in two versions with identical mathematical structure but slightly different cover stories.................................................................................................................. 42
Table 7: CLASS response items in the Real-World Connections category. These items are scored on a 5-point Likert scale: strongly agree, agree, neutral, disagree, and strongly disagree. Responses to items 28, 30, and 37 are considered favorable if the student chooses ‘strongly agree’ or ‘agree’. Responses to item 35 are considered favorable if the student chooses ‘strongly disagree’ or ‘disagree’. ................................................................. 46
Table 8: Class sizes and participation rates for the CLASS survey in Physics 100 from 2006 to 2009. In 2006 participation in the survey was strictly voluntary. In 2007 through 2009 1% of course grade was given for participation in both the pre- and post-tests.................................................................................................................................................. 47
Table 9: Instructor changes and number of CLASS survey participants in Physics 100 from 2006 to 2010................................................................................................................................. 52
Table 10: Summary of questions in exploratory post-course interviews. Students were asked to read these questions aloud, comment on whether they agreed or disagreed with them on a 5-point Likert scale, and asked to explain their reasons for their responses. Responses to questions with a * next to the item number are considered favorable if the student disagrees with the statements. ................................................................. 62
Table 11: Summary of structured real-world connection participant demographics. The last column of the table gives the students’ score on the CLASS survey Real-World Connections category. A higher number means the student reports more expert-like beliefs about the relationship between physics and the real world. .................................................. 77
Table 12: Summary of triggers for real-world connections. The main trigger categories are listed to the left and the subcategories are listed underneath these. The number in parentheses after each trigger is the number of times it was coded over the whole data corpus. Triggers that were generally cited as enabling real-world connections are written in bold font, those that were cited as inhibiting real-world connections are written in italics, and those that could be cited as either enabling or inhibiting real-world connections are written in standard font. .................................................................................. 82
Table 13: Properties of scientific problems used to probe students’ perception of relevance to the real world. Columns 2-5 were coded by the researcher. The Environmental rating is based on the number of environmental triggers mentioned by the participants in study.

Table 14: Coding scheme for responses to Reality Link Questions. In each case, a code of 1 indicates the student reported that they perceived little or no real-world connection in that category, a response of 3 indicates a strong real-world connection, and a response of 2 is neutral or mixed.

Table 15: P-values of tests to examine the relationship between problem characteristics on student responses to Reality Link Questions. *(p < 0.1), **(p< 0.05), ****(p < 0.01).

Table 16: P-values of Kruskal-Wallis test to examine the impact of the interaction between Everyday Context and Money on real-world-connection questions. *(p < 0.1), **(p< 0.05), ****(p < 0.01).

Table 17: P-values of pairwise Mann-Whitney comparisons of average results between the three groups of problems. Group 1 is Strong Everyday Context and Money; Group 2 is Strong Everyday Context and No Money; Group 3 is Weak Everyday Context and No Money. *(p < 0.1), **(p< 0.05), ****(p < 0.01).

Table 18: Four behavioral clusters and associated epistemological frames. Scherr and Hammer argue that these behaviors in group problem-solving constitute evidence for students’ current approach towards knowledge and learning.

Table 19: Summary of audio and video episodes coded for validation of audio-only coding of epistemological framing.

Table 20: Inter-rater reliability for study of audio-only vs. video coding of epistemological framing. Frame transitions were coded to within 5 second accuracy. The inter-rater reliability was calculated as IRR = 1 - (errors) / (total duration coded).

Table 21: Example of Conceptual Discussion. The students’ focus is on figuring out what is going on in the situation and the implications for the force in the rope.

Table 22: Example of Procedural Discussion. The students’ focus is on figuring out what they should be calculating.

Table 23: Characteristics of Procedural Discussion and Conceptual Discussion frames.

Table 24: Summary of epistemological framing coding scheme.

Table 25: Transcript to illustrate Procedural Discussion, Conceptual Discussion, and Off-Topic epistemological frames.

Table 26: Inter-rater reliability testing for epistemological framing coding scheme. The IRR is calculated as 1 - (total of errors that are greater than 6 seconds) / (total time coded).

Table 27: Inter-rater reliability testing for Real-World Connections coding scheme. The IRR was calculated as 1 - (number of RWC coded more than 6 seconds from the other coders’ RWC) / (total number of RWC coded).
Table 28: Types of real-world connection identified during collaborative group problem-solving in introductory physics. ................................................................. 158
Table 29: Example of Real-World Connection as Interpretation. ............................... 160
Table 30: Example of Real-World Connection as Evaluation. ...................................... 161
Table 31: Example of Real-World Connection as Personalization. .............................. 162
Table 32: Example of Real-World Connection as Meta-Statement. ............................ 163
Table 33: Summary of time spent, Real-World Connections, and frequency of real-world connections by epistemological frame. ....................................................... 165
Table 34: Transcript of RWC cluster in the Meta frame. These students have just read a recitation problem that states the stopping distance for a car traveling 50 km/h is 20 meters and are commenting on the realism of the problem itself during this segment. The “−1” in the RWC column indicates that statement was coded as a negative RWC due to being explicitly negative about the realism of the problem. A “1” indicates a RWC that is not explicitly negative about the realism of the problem. ............................... 168
Table 35: RWC by frame for each episode. The High group is episodes that have 32 or more RWC. The Low group is groups that have 18 or fewer RWC. ......................... 171
Table 36: Percentage of RWC in a particular frame that are a certain # of seconds after the previous RWC. The bottom row indicates the percentage that are more than 30 seconds after the previous RWC. ................................................................. 177
Table 37: Illustration of RWC clusters in the Conceptual Discussion frame. ............... 179
Table 38: Illustration of RWC in the Worksheet and Procedural Discussion frame. ...... 180
Table 39: Illustration of RWC in the Conceptual Discussion and Off-topic frame. The students have just calculated an answer and are commenting on it. ......................... 181
Table 40: Aggregate percentage of each problem-solving step spent in each Frame. This is calculated as (Total time in frame during this prompt for all groups) / (Total time spent in this prompt for all groups). ................................................................. 183
Table 41: The Total number of RWC by prompt for the High and Low RWC categories. The High RWC groups have 32 or more RWC (N=6). The Low RWC groups have 18 or fewer RWC (N=8). ................................................................. 185
Table 42: Example of spontaneous use of real-world knowledge to interpret the result of a calculation............................................................................................... 191
Table 43: Snippet from the Error-Checking and Sensemaking step for one of the Low RWC groups, illustrating the cursory consideration of the sensibility of answers that is typical of the data in this study. ................................................................. 193
Table 44: Snippet from the Error-Checking and Sensemaking step for one of the High RWC group, illustrating a cursory consideration of the sensibility of answers. ....... 193
Table 45: Number of negative RWC broken down by episode number and problem solving prompt......................................................................................... 196
Table 46: Transcript of negative RWC cluster based on objection to a detail of the tutorial.
These students have just read a recitation problem that states the minimum stopping distance for a car traveling 50 km/h is 20 meters. A “−1” in the RWC column indicates a statement that was coded as a negative RWC, while a “1” indicates a positive RWC.

Table 47: Transcript negative RWC cluster based on objection to a detail of the tutorial. These students are discussing the assumptions for their model. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.

Table 48: Transcript of example negative RWC cluster based on objection to the motivation for a calculation. These students have just read a recitation problem that states that a fridge will be secured in the back of a pickup truck with exactly two ropes. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.

Table 49: Transcript of example negative RWC cluster based on objection to the motivation for a calculation. These students have just read a recitation problem in which a doctor has advised the patient to avoid more than 450 Newtons of force on their broken rib. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.

Table 50: Transcript of example negative RWC cluster based on objection to the motivation for a calculation. These students are discussing the assumptions necessary to solve a problem involving moving a fridge. A “−1” in the RWC column indicates a statement that was coded as a negative RWC, while a “1” indicates a positive RWC.

Table 51: Transcript of example negative RWC cluster based on objection to using physics instead of common sense. These students are discussing the assumptions necessary to solve a problem involving moving a fridge. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.

Table 52: Transcript of example negative RWC cluster based on objection to the suggestion that students would have experience with which to judge their answer to a problem that involves moving a fridge, where the truck carrying the fridge may crash. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.

Table 53: Transcript of example negative RWC cluster based on judgment that the goal of the tutorial is unrealistic. These students are discussing the recitation’s instruction to consider whether it is “safe to drive home”. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.

Table 54: Transcript of example vaguely negative RWC cluster. These students have been flipping through their notes searching for other assumptions to make for their recitation problem. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.
LIST OF FIGURES

Figure 1: Pre-post shift in favorable responses for the Overall and Real-World Connections categories on the CLASS survey. The shifts are calculated as %shift = %favorable_post - %favorable_pre for matched pairs of pre/post surveys. .................. 48

Figure 2: Pre-post shift in unfavorable responses for the Overall and Real-World Connections categories on the CLASS survey. The shifts are calculated as %shift = %unfavorable_post - %unfavorable_pre for matched pairs of pre/post surveys. ........ 48

Figure 3: Pre-course Favorable CLASS survey scores for 2006 - 2010 in the Overall and Real-World Connections categories .......................................................... 50

Figure 4: Pre-course Unfavorable CLASS survey scores for 2006 - 2010 in the Overall and Real-World Connections categories .......................................................... 50

Figure 5: Pre-post shift in favorable responses for the Overall and Real-World Connections categories on the CLASS survey for the two sections that had the same instructor for 2006 and 2007. .......................................................... 53

Figure 6: Pre-post shift in unfavorable responses for the Overall and Real-World Connections categories on the CLASS survey for the two sections that had the same instructor for 2006 and 2007. .......................................................... 53

Figure 7: Pre-post shift in favorable responses for the Overall and Real-World Connections categories on the CLASS survey for the sections that had the same instructor each year. .......................................................... 55

Figure 8: Pre-post shift in unfavorable responses for the Overall and Real-World Connections categories on the CLASS survey for the sections that had the same instructor each year. .......................................................... 55

Figure 9: Favorable CLASS shift results for the 2009 year, broken down by the week in which students completed their post-test. In this year, the post-testing period was open for two weeks, instead of the usual one week. .................. 57

Figure 10: Unfavorable CLASS shift results for the 2009 year, broken down by the week in which students completed their post-test. In this year, the post-testing period was open for two weeks, instead of the usual one week. .................. 57

Figure 11: Main coding schemes and correlation studies in Chapter 6. ................ 116

Figure 12: Summary of reasons for inter-coder error when coding epistemological framing with audio only vs. audio plus video. .......................................................... 125

Figure 13: Boxplot of frequency of RWC in different Frames across the data set (N=14 episodes). The dark bar shows the median, the box shows the 25th - 75th percentiles, and the whiskers show the range of the data. Outliers, more than 1.5 times the inter-quartile distance, are marked with circles. The Triangle symbols mark the average value for each episode. .......................................................... 166

Figure 14: Histogram of number of RWC by episode. The episodes are split into two categories: The High RWC groups have 32 or more RWC (N=6). The Low RWC groups have 18 or fewer RWC (N=8). .......................................................... 172
Figure 15: Time spent in each frame by High / Low RWC category. The High RWC groups have 32 or more RWC (N=6). The Low RWC groups have 18 or fewer RWC (N=8).

Figure 16: Frequency of RWC in each frame by High / Low RWC category. The High RWC groups have 32 or more RWC (N=6). The Low RWC groups have 18 or fewer RWC (N=8).

Figure 17: Boxplot of number of RWC per group by problem-solving step for the High RWC groups (32 or more RWC, N=6 groups) and the Low RWC groups (18 or less RWC, N=8 groups).

Figure 18: Boxplot of frequency of RWC by problem-solving step for the High RWC groups (32 or more RWC, N=6 groups) and the Low RWC groups (18 or less RWC, N=8 groups).

Figure 19: Total number of RWC as a function of time after the Assumptions prompt by High and Low RWC groups. The shaded background shows the fraction of groups that are still working in the Assumptions step at that time.

Figure 20: Total number of RWC as a function of time after the Solve prompt by High and Low RWC groups. The shaded background shows the fraction of groups that are still working in the Solve step at that time.
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If I have forgotten anybody in this brief note, know that the fault is mine and not theirs.
DEDICATION

This dissertation is dedicated to my wife Donyne O’Coffey and my son Felix. Without their love and support this work would not only have been impossible, it would have been meaningless. They have been my greatest friends, my greatest inspiration, and my greatest teachers, and this work is dedicated to them.
1 INTRODUCTION

1.1 Motivation: Useful Education

It is a great tragedy of our modern education system that much of what is learned will never be used outside the classroom it is learned in. Teachers may teach and students may learn the topics on the course curriculum without ever considering whether the learned knowledge has any application or relevance to the world beyond the classroom walls.

Considering the ways that an education might be useful outside the classroom can offer instructors a significant new perspective on their teaching. In 2007 the instructors of the University of British Columbia’s Physics 100 course (the introductory physics course for non-majors) started asking themselves: What use could an introductory physics course be to a student who doesn’t continue in physics? This question was very pertinent to their course in particular. Of the 800 students taught in this course every year, less than half a percent of them would carry on in physics beyond the first-year sequence. Despite this, the course used the same textbook and the same pedagogical approaches used by the courses for physics majors. The investigation undertaken by the Physics 100 instructors of how to offer a physics education that would be useful to students outside the classroom led to a comprehensive transformation of the UBC Physics 100 course, and set the stage for this dissertation.

In this dissertation, I explore three educational goals that, if achieved, can help formal physics education to reach beyond the classroom:

1. integration of formal physics knowledge with students’ everyday knowledge of physics
2. development of students’ belief in the relevance of physics to the real world, and
3. development of flexible problem-solving skills.

In the remainder of this introduction, I will briefly describe the motivation and some of the previous research relevant to the above goals. Then I will describe my approach to
investigating each of these goals, and present the research questions addressed in this thesis. Finally, I will introduce the studies that I have conducted to address those questions and provide an overview of the entire dissertation.

1.2 Changes to Physics 100

In order to promote students’ perception of the relevance of physics to the real world and to enable them to develop flexible real-world problem-solving skills the Physics 100 course at UBC was substantially transformed in the fall of 2007. These changes are described in detail in chapter 2, but are summarized briefly here.

Several strategies were employed in order to address one or more of the above goals. First, every physics problem in the course was presented in terms of a realistic everyday context. This included all lecture examples, homework problems, and weekly recitation problems. Second, context-rich problems were adopted for the weekly recitation sessions [1]. These problems require students to work in groups to solve a single complex problem using a structured problem-solving method, and were redesigned to encourage students to make use of their real-world knowledge in order to attain a solution. Third, to address the challenge of applying simple physics to real-world problems which are often ill-defined and complex, the course emphasized the role of modeling in problem solving. The practice of making reasonable assumptions in order to represent a real system in a simplified quantitative representation that is amenable to calculation was demonstrated in lecture and was explicitly emphasized during the recitation sessions. Finally, the course content was substantially changed in order to enable discussion of the physics of everyday circumstances such as home heating, as well as the physics relevant to social and environmental issues such as energy conservation and climate change. These changes are described in detail in section 2.4.

1.2.1 Integrating Physics and Real-World Knowledge

One way that physics education can be relevant outside the classroom is by enabling students to learn formal physics knowledge that is well-integrated with their everyday knowledge. Here, “well-integrated” means that the physics concepts are understood in terms of everyday knowledge and vice versa. Enabling students to
connect to their existing ideas about physics helps them to learn: Indeed, integration into their existing framework of knowledge and experience is what gives new ideas meaning [2].

A wide variety of research has been done on the role of students’ informal and intuitive knowledge in learning physics content. (for a review, see Ref. [3]) Much of this research focuses on the ways in which students’ informal and intuitive knowledge may prevent the learning of canonical physics concepts. A common way of dealing with students’ unproductive intuitions is to “confront” the informal knowledge to demonstrate its incorrectness [4].

However, some researchers advocate refinement of students’ intuition rather than refutation of it [5]. Sherin has argued that, when physics knowledge and informal intuition are accessed simultaneously, this creates opportunities for intuition to change and evolve, and he suggests that this process may eventually develop the qualitative intuition of an expert [6]. Pugh, in his research on student use of science information outside the classroom, suggests that “applying learning to real-world situations under the direction of the teacher in class may be the first step to applying learning in one’s everyday experience” [7].

In order to help students integrate their real-world knowledge and intuitions with their formal physics knowledge, Physics 100 was revised to present every lecture example, homework problem, and recitation problem in an everyday context. In this dissertation I examine the success of these changes by looking at students’ discussions during the weekly recitation sessions to identify the ways in which they make use of their real-world knowledge. I also examine some of the factors that influence these real-world connections.

1.2.2 Beliefs About Relevance of Physics

Because physics involves the study of matter, energy, and motion, it would seem trivially easy to teach physics that is relevant to the world outside the classroom; it could be argued that physics is relevant to every process in the universe. However, as Pugh observed in his studies of use of science outside the classroom, “The ability to
apply knowledge does not guarantee that students actually will apply their knowledge” [8]. He suggests that the belief in the relevance of science to the outside world is an important precursor to the actual use of science in the outside world [7,8]. More generally, students’ beliefs about the nature of physics and learning have also been shown to impact their choice of learning strategies, their satisfaction in the field, and their subsequent persistence in physics [9-12].

Unfortunately, studies of students’ beliefs about physics have revealed that many novice students do not perceive physics to be meaningfully related to their everyday world [13,14]. Furthermore, those same studies show that students’ beliefs typically become less favorable during their first introductory physics course, which can be attributed to implicit messages students receive about physics from typical treatment in curriculum [15,16]. According to these surveys, the only courses that have been shown to help students to view physics as being more coherent, more connected to the real world, and less about memorization of formulae are courses that have an explicit emphasis on highlighting and discussing students’ and scientists epistemological beliefs [15,17-19].

This underscores the influence that pedagogy can have on students’ beliefs. The potential to positively affect students’ beliefs motivated the transformation in Physics 100 aimed at improving students’ perception of the relevance of physics. In this dissertation, I examine students’ perception of the relevance of various physics problems to the real world, both in interview studies and via analysis of their discourse during problem solving.

1.2.3 Problem Solving

A third way that physics education can be relevant outside the classroom is by teaching students skills and habits of mind that enable them to solve complex problems. Teaching such “problem-solving skills” is a commonly cited goal of introductory physics education, and there is a host of research on methods for teaching these skills to students. Many researchers advocate use of a structured problem-solving method as a means to enable students to develop advanced problem-
solving skills and to promote integration of conceptual and procedural knowledge (e.g. [1,20,21]).

The Physics 100 course adopted a structured problem-solving strategy for use in lectures and the weekly recitation sessions. In this dissertation I examine how this mandatory problem-solving strategy influenced students’ use of conceptual and real-world knowledge in discussions during their weekly recitation sessions.

1.3 Research Approach and Research Questions

In this section I describe my approach to investigating each of these strategies, and present the research questions addressed in this thesis.

It is important to note that, although these studies are conducted within the context of the transformation of the Physics 100 course, and chapter 3 is concerned with evaluating the impact of those changes, that is not the principal focus of this dissertation. Rather, this work is an exploration, in the spirit of Interpretive Research [22], of the different ways in which students perceive connections between physics and the real world and of the factors that influence such connections.

1.3.1 Research on Beliefs About Relevance Of Physics

In this dissertation I examine how students’ beliefs about physics changed over the course of Physics 100. Specifically, I investigate whether the course transformation had the intended effect of promoting students’ perception of the relevance of physics to the real world.

In order to evaluate the effect of the course transformation I rely on the only two sources of information available on the pre-transformation course: the CLASS survey of student beliefs about physics [14], and the instructors’ recollections of the pre-transformation course. The CLASS survey assesses students’ beliefs about physics in a wide variety of areas, including their belief in the relevance of physics to the real world, and their beliefs about the nature of knowledge in physics and how it is developed. This survey was conducted in 2006, the year prior to the transformation,
and the measured decline in students’ perception of the relevance of physics to the real world was one of the motivating factors for the course changes.

Using these two sources of information, I address the research question:

Research Question 1: Did the changes to Physics 100 improve the impact of the course on students' beliefs regarding the relevance of physics to the real world?

1.3.2 Research on Integrating Physics and Real-World Knowledge

Because of the possibility that working with physics and informal knowledge together may enable better integration between them, I have studied the ways in which students make connections between these two types of knowledge.

In prior work, I (and others) have examined students’ connections between formal physics and the real world by looking at their ability to apply physics to written problems that are set in an everyday context [23,24]. Another approach has been to examine teachers’ and students’ mentions of real-world science within a classroom [25].

In my work, I follow Sherin’s approach of examining students’ discourse during problem-solving to identify instances where they make use of their informal intuition and everyday knowledge in concert with physics knowledge to clearly identify the co-activation of real-world and physics knowledge that leads to integration of these two types of knowledge [6]. My dissertation addresses the following two research questions:

Research Question 2: In what ways do students make connections between physics and the real world?

Research Question 3: What influences whether and how students make connections between physics and the real world?

1.3.3 Research on Conceptual Discussion During Problem-Solving

The problem-solving strategy used in the Physics 100 recitations includes several steps that are explicitly intended to induce students to make use of their conceptual
and qualitative knowledge both prior to and following their main calculations. As I will describe in Section 6.2.3, several published problem-solving strategies also include steps with the same intention [1,20,21].

These strategies are motivated by studies in differences of how experts and novices solve problems which show that experts are more likely to make use of qualitative reasoning before and after employing mathematical methods in solving physics problems [26,27]. Many strategies enforce adherence to the expert-like strategy by requiring students to perform each step via a marking rubric or worksheet. [1,20,21]

The use of such a strategy and the requirement that students follow each step implicitly assumes that the students will, in some meaningful way, follow the instructions laid out in each step. Given that these strategies are intended to induce students to make use of their conceptual knowledge at appropriate times during the problem-solving process, I examine students’ discussions to investigate whether these strategies are successful at doing so. The fourth main research question in this dissertation is:

Research Question 4: To what degree are structured problem-solving methods effective at promoting the use of conceptual and qualitative knowledge at the intended times in the solution process?

1.4 Dissertation Overview

In subsequent chapters of this dissertation I first provide a thorough description of the changes made to the Physics 100 course, and then describe four studies that each address one or more of the research questions. These studies are introduced in the following subsections, and then described in detail in chapters 3 through 6. In chapter 7 I discuss the results and implications of each study and suggest some future work.

For reference, the major studies and their individual research questions are listed in Table 1 below. The first column of Table 1 lists the main research questions. Then in each subsequent column I list the ways that research question is addressed by the individual chapter.
<table>
<thead>
<tr>
<th>Overall research questions</th>
<th>Study of Changes in Students' Beliefs (Ch. 3)</th>
<th>Exploratory Post-course interviews (Ch. 4)</th>
<th>Structured RWC Interviews (Ch. 5)</th>
<th>Framing and RWC in Collaborative Group Problem-Solving (Ch. 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did the changes to physics 100 improve students' beliefs regarding the relevance of physics to the real world?</td>
<td>Did the changes to physics 100 improve students' beliefs regarding the relevance of physics to the real world?</td>
<td>In what ways do students see physics as related to the real world?</td>
<td>In what ways do students make use of their real-world knowledge during collaborative group problem-solving?</td>
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<td>In what ways do students make connections between physics and the real world?</td>
<td></td>
<td>What factors do students cite as affecting their belief in the relevance of physics to the real world?</td>
<td>What features of scientific problems do students see as connected to the real world?</td>
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<td>What influences whether and how students make connections between physics and the real world?</td>
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<td>How does students' framing affect whether and how they make use of their real-world knowledge during collaborative group problem-solving?</td>
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<td>To what degree are structured problem-solving methods effective at promoting the use of conceptual and qualitative knowledge at the intended times in the solution process?</td>
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<td>How does the structured problem solving strategy affect whether they make use of their real-world knowledge during collaborative group problem-solving?</td>
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Table 1: Overall dissertation research questions and sub-questions by chapter.

1.4.1 Study of Changes in Students' Beliefs

Chapter 3 describes the study conducted to examine the impact of the Physics 100 course changes on students’ beliefs. In order to examine beliefs that affect how students make use of scientific knowledge in their everyday lives, I am particularly concerned with students’ perception of the relevance of physics to the world outside
their classroom. To examine students’ perception of real-world connections in physics I use the CLASS survey of students’ attitudes and beliefs about physics [14], which was performed as a pre- and post-test prior to the transformation as well as in each year since. The results from this survey from the years 2006 – 2009 are compared, and differences in instructional faculty, student demographics, and surveyed populations are incorporated into an ANOVA statistical analysis to explore the impact of the course changes.

1.4.2 Exploratory Post-Course Interviews

Chapter 4 describes the Exploratory Post-Course Interviews, a semi-structured interview study that explores students’ perceptions of the course changes. The interviews are structured around individual questions from the CLASS survey [14], all in the form of a statement that students are asked to agree or disagree with on a five point scale. In the interviews students were asked to respond to various CLASS question prompts and explain their answers, as well as to give free-form comments on the course changes.

This study addresses research questions 2 and 3 by examining the ways in which students see physics as related to the real world and the factors that they cite as affecting their belief in the relevance of physics to the real world. Because the CLASS survey questions are used as the basis for the interviews, this study also serves to illuminate the students’ reasons for their CLASS survey responses within the specific context of the Physics 100 course.

This study was conducted after the first year of the course transformation and informed the development of the course’s lecture materials, homework problems, and recitation problems for the next year. Some of the students’ comments during this study helped to illuminate the difference between the faculty’s (and my) perception of physics that was relevant to the real world and the students’ perceptions of the same.

This study illuminated several possibilities for major factors that influence students’ perception of the relevance of physics problems to the real world. My new
understanding of these factors informed the Structured Real-World Connections interview study which examined these factors in a more systematic way.

1.4.3 Structured Real-World Connections Interviews

Chapter 5 describes the Structured Real-World Connections Interview study. Based on the results of the prior study, I developed a diverse set of scientific and mathematical questions, each of which had one or more characteristics that I expected would lead students to either rate the question as very relevant or irrelevant to the real world. For example, some questions were set in an everyday context such as a bus, others were set in an unusual context such as outer space, and others were completely abstract and had no context at all. A wide variety of undergraduate students were recruited to give their judgment of the relevance of these problems in an interview format and to explain the reasons for their judgments. The interview results were subsequently coded to identify the problem features that students cited as motivating their judgment of relevant or irrelevant to the real world. These judgments were also subsequently coded and analyzed to identify which problem features were significantly correlated with high overall ratings of relevance.

This study further examined research question number 3 and broadened it to include questions from science and mathematics disciplines other than physics.

1.4.4 Epistemological Framing and Real-World Connections in Structured Group Problem-Solving

The results from the two interview studies above informed the development of the Physics 100 recitation problems, which were designed to promote the perception of relevance of physics to the real world and to encourage students to make use of their everyday knowledge within the recitation context. In chapter 6 I describe the fourth study, which examines students’ response to these recitation problems to further illuminate the types of real-world connections that they make and to identify factors that promote or inhibit those connections.

In this study I further examine research question 2 by analyzing students’ discourse while they engage with their normal weekly recitation problems. I identify
moments when students make use of their real-world knowledge within this context, and identify a taxonomy of different types of these Real-World Connections (RWC). I make use of the Resources and Framing theoretical framework to allow me to clearly define when a Real-World Connection occurs [28,29]. Briefly, this framework describes knowledge as consisting of fine-grained interconnected resources. Resources may be declarative, procedural, epistemological, or intuitive [30]. Any facts or principles that we make use of in order to reason may be considered to be resources, including ideas about knowledge and learning. The use (or activation) of a particular resource may be context-sensitive and subject to different activation in different contexts. For the purposes of this study, I define the use of real-world resources within the recitation context as a Real-World Connection. I argue that these Real-World Connections enable students to integrate their physics knowledge with their informal knowledge and also have the potential to influence students’ perceptions of the relevance of physics to the real world.

One of the factors that I examine and correlate with students’ Real-World Connections is their epistemological framing. An epistemological frame is a person’s implicit sense of the nature of the activity they are engaged in, and corresponds to a network of epistemological resources that tend to co-occur in a stable fashion. The resources that are activated in a particular epistemological frame may include judgments of which knowledge is valid, what constitutes progress, and how that progress can be achieved within that activity. In this way, frames can affect students’ approach to learning and affect which other resources they bring to bear in a particular situation [31]. In this study I correlate moments when students make a Real-World Connection with their epistemological framing to demonstrate how framing regulates the use of their everyday resources.

I also examine how the structured problem-solving method used in the Physics 100 recitations correlates with students’ Real-World Connections and their epistemological framing. This allows me to investigate research question 3 to determine how the strategy influences their Real-World Connections and research
question 4 to determine how the structured problem-solving strategy influences students’ use of conceptual and qualitative knowledge during problem-solving.
2 DEVELOPMENT OF PHYSICS 100

Because my research was largely conducted in and around the transformation of UBC’s Physics 100 course in 2007, this chapter provides background on that course and the descriptions of the changes.

2.1 Background of Physics 100

Physics 100 at the University of British Columbia is an algebra-based introductory physics course offered to those students who did not take senior high school physics.

Prior to the course changes outlined in this thesis, the Physics 100 syllabus and format was similar to many North American introductory physics courses. The course consisted of 3 hours of weekly lectures supplemented with bi-weekly alternating 3-hour laboratory sessions and 2-hour optional recitation sessions where students worked in groups on practice problems. The course followed a common sequence of topics in mechanics, DC circuits, and geometrical optics. To improve student engagement, the faculty used an electronic response system (also known as clickers) to periodically ask short questions during lectures.

Because Physics 100 is required for many of UBC’s Arts and Science programs the student population is very diverse. Approximately 60% of the students are B.Sc. students, but the vast majority of them are not intending to major in physics and are required to take only one physics course in addition to Physics 100. The remainder of the students are human kinetics, food and nutrition science, forestry, or arts students, and Physics 100 is likely the only physics course they will take in their undergraduate program.

2.2 Motivation for Changes

After teaching the course for several years, the instructors of Physics 100 were concerned that students were not being well-served by the course content and format. This course presented physics content in ways that might be useful for further study in physics but few, if any of its students would be pursuing further studies in physics. The overriding question for developing a new version of this course was: other than a fulfillment of requirements for a degree program, what use can a physics course be to a student who is not principally interested in physics?
This perspective on making the course useful to the students underlies several complementary motivations for making changes to the course. These are discussed in the sections below.

2.2.1 Students’ Understanding of Societally Relevant Issues

Because the students in Physics 100 would likely study very little physics in their university careers, the instructors hoped to teach them something that would be useful outside physics class. To that end they considered both the applications of physics in other courses and the applications of physics to real-world problems and issues. The key real-world issues the instructors wanted to address were energy conservation and climate change.

An understanding of issues in climate change and energy conservation are crucial to the success and prosperity of society but the feeling of the instructors was that the public (including many journalists) may not understand them very well. Worse, it seemed that many people adopted an attitude of either taking scientific statements in the media at face value or writing off all science as ‘just theories’; taking the presence of scientific debate as an indicator that nothing in these issues was settled or worthy of action.

The instructors hoped that including a discussion of these issues as well as demonstrating techniques for critical analysis of arguments presented in the media might help to raise their students’ understanding of these issues as well as their ability to meaningfully engage with these issues in their everyday lives. They intended that this course would contribute to the students’ scientific literacy, which for them meant that they would understand enough about science content and the nature of professional science that they would be willing and able to use their own knowledge to evaluate scientific messages in the media and take action to engage with socioscientific issues.

2.2.2 Retention

The instructors were also concerned about students’ poor retention of facts and concepts learned in physics class. It had become clear from their prior experience as
well as academic research that the learning strategies employed by students, which often involved last-minute cramming and “memorization” of textbooks, resulted in shallow and temporary knowledge [32,33]. This was particularly true of students in Physics 100 who would take only one or two physics courses, and would have little opportunity to re-learn and deepen their understanding of physics concepts in later courses. The Physics 100 instructors were concerned that unless they changed their students’ approach to learning in the course their students would literally forget everything they learned.

2.2.3 Perception of Relevance of Physics

The instructors came to believe that a key piece of this problem of retention was the issue of relevance: the Physics 100 students did not see the physics presented as being relevant to anything outside of the physics classroom, and therefore had no motivation to learn it in a deep way. The head instructor’s feeling was “Even the best student will expel [physics] knowledge if they don’t see it as being relevant”.

2.2.4 Decline in CLASS Survey Scores

The instructors’ concern about the students’ perception of the relevance of physics was also highlighted by research on student attitudes and beliefs about physics. Several researchers had examined students’ attitudes and expectations on several areas relevant to learning in physics, such as students’ perception of knowledge and learning, relevance to the real world, and the nature of problem solving in physics [10,13].

In the 2006 Physics 100 course, the Colorado Learning and Attitudes towards Science Survey (CLASS) was administered as a means of measuring how students’ attitudes and expectations towards physics had changed after taking the course [14]. The CLASS survey uses 42 statements about physics and learning with which the students are asked to agree or disagree on a 5-point Likert scale. Each statement has a favourable or unfavourable response, as defined by the response that is consistently given by physics professors and other expert physicists. As is often the case in traditional introductory physics courses, the average CLASS score of Physics 100 students in 2006 became less favourable over the course of instruction [34]. This
suggested that the course was actually having a deleterious impact on student attitudes toward physics, reinforcing undesirable attitudes and assumptions about the nature of physics and learning.

This negative impact in Physics 100 was especially concerning because the instructors felt that these negative opinions would be many students’ last impression of Physics, and could colour the way their students perceive physicists and scientific information for the rest of their lives.

### 2.2.5 Real-World Problem-Solving Skills

The instructors expected that including material on energy conservation and climate change would provide students a better understanding of those issues, but they felt that physics had more to offer than specific knowledge about particular issues. The instructors felt that this course represented an opportunity for students to learn how to model complex, novel problems and estimate solutions using quantitative problem-solving methods.

These modeling and estimation skills are one of the hallmarks of expert problem-solving, and the instructors knew from their own experience that they can be very useful in a broad variety circumstances, both academic and everyday. They felt that traditional physics courses over-emphasized purely mathematical aspects of problem solving, without addressing how mathematical representations are created in the first place. In order to enable students to learn flexible problem-solving skills, the instructors felt it was important to demonstrate how simplified models were created from realistic situations and how the results of calculations can be checked against our expectations of the real situation. They hoped that highlighting the diverse practices needed for solving real-world problems would help students develop a more complete set of skills for tackling novel complex problems.

### 2.3 Goals of Changes

After much discussion, the Physics 100 instructors settled on three major goals for their course. They wanted to:
1. educate their students about socially relevant issues

2. enable them to learn how to apply physics to other scientific issues in the public sphere

3. encourage students to see physics as relevant to themselves and to their lives

The instructional team was not aware of any prior pedagogical interventions focused on use of connections to everyday problems and contexts as a tool to promote student engagement and learning in university-level introductory physics. They felt that their goals were attainable within the introductory physics setting, and set about developing a curriculum and pedagogy that would support these goals.

2.4 Changes to Physics 100

In order to meet their goals for this course I worked with the Physics 100 instructors to make changes in a wide variety of aspects of the course. In an endeavour to offer physics education that would be useful to students outside of the classroom we added several physics topics relevant to thermal physics, climate change and energy production to the course content, reworked many examples and problems to put them in a more everyday context, increased the course’s focus on problem-solving skills by adopting a prescribed problem-solving strategy in lecture and recitations, and implemented a research project.

These changes are described in detail in the following sections. These descriptions are not intended to be comprehensive, but rather to give the reader a sense of the course which was used as a setting for my research. Special attention is paid to the changes to the course’s recitations, which was the setting for one of the main studies in this dissertation.

2.4.1 Everyday Context

In order to enable students to apply physics knowledge in everyday situations and to demonstrate the relevance of physics to the real world, the faculty felt that it would be crucial to situate the physics in the context of the students’ everyday world. I worked along with the course faculty to find specific example problems, diagrams, and instructional methods that would present this new course syllabus in terms of the
students’ everyday experience. As much as possible, every example in the lectures, every homework question, and every recitation question was set in a context that students could plausibly have encountered in their lives.

This task proved to be quite challenging. Traditional physics instruction is often engaged in the business of reduction: each physical effect is discussed and demonstrated in absence of other effects, and far from the complex reality of everyday situations. Unfortunately examples that are rooted in the everyday world of the students and cleanly demonstrate the action of a single physics principle are rare: most everyday situations involve a combination of several influences which makes any discussion of the physics quite complicated, especially for novice learners.

In order to address this problem we identified several “models” that we wanted to teach: example calculations describing situations that were relevant and useful which could act as anchoring ideas to help motivate the development of the constituent physics. Examples of these models include: the energy flows and temperature in a home, the energy balance and temperature of the earth, the fuel consumption of a car or bus, and the efficiency of a system of electricity transmission. Working with these complex models meant that we needed to foreground the importance of simplifying assumptions in rendering complex everyday systems tractable.

While the emphasis on real world relevance of course content is not new in the global sphere of education, this commitment to present an entire introductory university physics course in an everyday context was ground-breaking. However, as discussed below in section 4.5, it became clear after the first year of transformation that the faculty’s perception of what was ‘relevant’ and ‘everyday’ did not always match the students’ perception.

2.4.2 Course Content

The idea of conservation of energy was used as a touchstone throughout the course, making connections between the various applications to thermal physics, mechanics, and electricity. Energy was expanded from a single unit in mechanics to a unifying theme for the entire course. A discussion of fuel efficiency and energy
consumption in transportation was added to the material on mechanics, and the unit on electricity was contextualized in discussions of household energy consumption.

Because of the prevalence of energy in the curriculum, the faculty decided to try to construct a lesson sequence that started with a discussion of energy. This decision was not easy; it was a challenge to find a new way of introducing this material in a way that deviated from the traditional method of introducing energy only after kinematics and dynamics had been introduced. On one hand, we felt that observable properties of objects such as velocity and height would be easier to explain to students, so from this perspective it seems sensible to use the more traditional approach of discussing the more abstract concept of energy only after kinematics and dynamics have been thoroughly explored. However, I suggested that energy as a scalar quantity might be mathematically easier to deal with at the beginning of the course than the vector trio of position, momentum, and velocity, and might therefore be more accessible to students at the beginning of the course. In the end we all agreed that the course should be “about energy”, and so the faculty agreed to try introducing energy at the beginning of the course and referring to this concept throughout. It is clear that the faculty believed that learning about energy was relevant to their students.

In support of this principle and the goal of educating the students about socially relevant issues that they could connect to their everyday lives several topics were added and some were removed from the course. These are discussed below

2.4.2.1 Thermal Physics and Climate Change

One of the key topics we wanted to address was the physics of climate change. One of the other professors on the development team had already been teaching the physics of home heating, a system that can be modeled using many of the same physics concepts as those used to model the Earth’s thermal equilibrium. The problem of understanding home heating seemed like the perfect context to motivate the development of the thermal physics required for climate change.
For this reason we added a quantitative treatment of conduction and radiation and a qualitative discussion of convection to the course. These concepts were used to develop a model of thermal equilibrium in home heating and subsequently used to discuss the radiative energy balance of the earth and its relevance to climate change.

The faculty agreed that climate change was a worthwhile topic to teach, but were concerned about the challenge of interpreting this very complex system for an introductory audience. However we found an introductory geoscience text that offered several perspectives on how simple models of climate change could be used to illustrate important characteristics of the Earth’s energy system [35]. These models neglected all dynamics of the atmosphere and treated it simply as a single layer with different absorption for different wavelengths of light. The instructors agreed that this model would strike a balance between simplicity and complexity, and would allow us to discuss important features of the Earth’s energy balance and highlight the critical role of the absorption of thermal energy by the atmosphere in determining the surface temperature of the Earth.

2.4.2.2 Air Resistance and Energy in Transportation

In order to allow for discussion of fuel consumption in transportation the basic physics of air resistance was added to the course. This, in combination with the course’s existing treatment of friction, supported the development of a model of the energy required for a car to travel at a constant rate which supplemented the existing curricular topic of the energy required to accelerate up to speed and to climb hills. Taken together, these principles allowed us to develop a simple model of fuel consumption in transportation and enabled comparisons between different modes of transportation (e.g. cars, buses, and trains) as well as between different engine types (e.g. internal combustion and electric vehicles).
2.4.2.3 Chemical and Metabolic Energy

In support of the goal of discussing the physics of everyday life, a discussion of chemical and metabolic energy was added to the course. We developed materials on the energy content of food and the energy consumption of various physical activities. This material ties into the discussion of thermal energy, as the occupants of a house help to heat its interior.

Introducing basic concepts of chemical energy also allowed us to discuss the fuel consumption of various forms of transportation and allowed us to draw analogies between a car’s consumption of fuel and a person’s consumption of food.

2.4.2.4 Power in Circuits

The course’s unit on DC circuits was re-factored to support a discussion of household electricity and power consumption. This meant introducing the concept of AC circuits, but the quantitative treatment was limited to RMS values. The concept of wires with finite resistance was added so that energy losses in electrical transmission could be quantitatively analyzed. The emphasis of this unit was in understanding power consumption in household circumstances, so much of the discussion centered on simple parallel circuits such as those found in household wiring. Detailed discussions of current and voltage in combined series and parallel circuits were eliminated.

2.4.2.5 Eliminated Topics

In order to make room for the added topics, we needed to eliminate some topics from the curriculum. The first major topic that was removed was conservation of momentum. The best real-world examples of this principle are collisions, but we felt that this application is a rare event, often removed from students’ typical lives and is principally of use to technical professionals such as accident investigators and, of course, physicists. Knowledge of momentum won’t help prevent a collision, and knowing about it afterwards won’t help you deal with one, so we felt that this topic had limited use for students that were
not intending to continue in physics. To make room for more applicable everyday concepts it was deleted.

Vector analysis was another topic that faculty felt was of limited value to this student population. For physics majors, the mathematical and conceptual tools of vector decomposition are essential, but the instructors’ experience had been that students in the Physics 100 course tended to regard these aspects of physics as purely formulaic and meaningless exercises. Therefore, vector analysis was cut from the mechanics curriculum along with all discussion of two-dimensional motion such as circular motion, cars on inclined planes, and projectile motion. While these topics certainly have real-world applications, we felt that the additional computational challenge was not warranted, and we could teach other topics that would be more valuable to students that were not as challenging.

As mentioned above, the discussion of circuits was significantly simplified to focus on energy transmission and consumption, and detailed discussion of current and voltage in complex DC circuits was eliminated.

Finally, the course’s two-week unit on geometrical optics was eliminated. We could not think of many compelling ways for a non-physicist to make use of simple geometrical optics, and so this topic was eliminated.

2.4.3 Problem-Solving Skills

The course transformation was significantly shaped by our consideration of what students would retain from this course. Research on student retention of concepts from introductory physics courses supported the faculty members’ experience that students retained little declarative knowledge from their prior courses [36]. However, the faculty believed that formal education can still be useful after one has forgotten the facts and formulae. They felt that often a way of approaching problems (such as the practice of cutting them down into smaller pieces) can help people interpret new situations. This led us to try to highlight things that we felt could be remembered:
problem solving approaches that might allow our students to address real world problems where physics might be fruitfully applied.

This perspective guided us to try to emphasize opportunities for students to learn how to apply physics in real world situations, rather than to simply amass declarative knowledge of physics content. The intent was not to do away with learning of declarative knowledge altogether, but to emphasize that the key skills of recognizing which knowledge is applicable and how to apply this knowledge.

To support the development of students’ problem-solving skills, we changed the weekly optional problem-solving sessions to mandatory group work on ‘context-rich’ problems based on those developed by Heller and Hollabaugh [1]. We also added a group research project to the course, where students develop a model and conduct a calculation in order to answer a question or make a decision about a real-world problem. Finally, in keeping with the recommendations of several physics education researchers (e.g. [20,21,37]), we adopted a structured problem-solving method that was used in the recitations and in lecture examples to demonstrate the process of applying physics in a novel situation. These changes are described in more detail below.

2.4.3.1 Modeling and Assumptions

Modeling is at the heart of physics analysis, and assumptions of rigidity, linearity, and frictionlessness are common in introductory physics courses in order to render problems tractable. Models are often communicated through simplified drawings and terse lists of assumptions and initial conditions.

However students are rarely exposed to the process of translating a complex real-world situation into a simplified model, and are often presented with only the abstracted result. This restricts their ability to make use of physics when confronted with a realistic situation, and contributes to their perception that physics is disconnected from reality. A student that only learns physics in the context of boxes on planes may never think of it when they are trying to move furniture across a carpet. Exposing the process of abstraction and
modeling is necessary in order to demonstrate the intimate connection between physics and the real world.

In order to highlight the importance of modeling and assumptions in physics we included some explicit discussion of these issues in the course. This process of making assumptions to simplify everyday situations was discussed in some detail throughout the course and was reinforced in the recitation sessions which required the students to make assumptions as a part of developing their own models. By discussing these techniques explicitly, we intended to address some of the students’ customary discomfort with making sweeping approximations.

Another strategy for dealing with students’ concern about making extreme simplifications such as ‘frictionless’ or ‘rigid’ was to search for real world examples where these could be justified via commonsense reasoning. This task was quite difficult, but we did find a few examples of situations where we believed students would accept such simplifications as being natural.

2.4.4 Structured Problem-Solving

Prior research in problem-solving has shown that novice problem solvers typically use a narrow suite of problem-solving strategies and unlike experts, frequently do little planning, visualization, or qualitative description prior to attempting a solution [27,38]. Since they are often skilled at pattern matching and algebraic manipulation of equations, these “plug and chug” techniques can allow students to score well on quantitative problems without an understanding of the qualitative physics [39].

To support the development of students’ problem-solving skills a structured problem-solving method was introduced in the Physics 100 lectures and recitations. Problem solving was presented to the students as a series of steps which scaffold the process of interpreting and structuring a problem, applying the appropriate physics principles to obtain a solution, and interpreting the solution. This method was used by the instructors during class and was used to scaffold the recitation problems
themselves with a series of written prompts and corresponding blank space for students’ work. Constraining novices to use more expert-like solution processes is a widely-used practice intended to foster their development of expert-like problem-solving skills. Among the pedagogies that advocate prescribed problem-solving methods are Heller and Hollabaugh’s context-rich problems [1], Teodorescu’s ACCESS protocol [20], and Van Heuvelen’s Active Learning Problem Sheets [21].

The specific steps used in Physics 100 were based on Heller et al.’s Cooperative Group Problem-Solving (CGPS) strategy but were modified over the first three years of implementation in Physics 100 as the instructors adapted to feedback from the TAs and researchers observing the course. The problem-solving strategy described below was the strategy we settled on in 2009, the third year of implementation. Each step is described below, and similarities to existing problem-solving schemes are noted.

2.4.4.1 Step 1: Interpret the Problem

Students often dive into calculation on a problem before they have attempted to interpret the situation, visualize what is happening, or identify the goal of the problem. This step directs students to make a quick sketch of the problem to aid in forming a mental picture and narrative of the physical process under discussion. This initial step mirrors the Heller’s CGPS step “Visualize the Problem”. Indeed, the context-rich problems used both in Minnesota and at UBC eschew illustration precisely to force students to engage in visualization and translation to visual representations.

This step also directs the students to identify the goal of the problem, something which is not always explicitly stated. As in the Minnesota context-rich problems, the task of identifying what must be calculated and/or compared is something we want the students to learn how to do. Explicit statement of the problem goal is also explicitly prompted by the first step of the GWU ACCESS protocol which directs students to “Assess the problem”. Curiously, identification of the problem’s quantitative goal is NOT explicitly prompted by the CGPS strategy, although it is certainly necessary for students to interpret the
goal of the problem in order for them to “Plan a solution” which is the third step of the CGPS strategy.

2.4.4.2 Step 2: Identify Relevant Physics

A key result of expert-novice problem solving research is that experts categorize physics problems based on their “deep structure” whereas novices focus on the “surface features” [26]. In order to encourage students to focus on the deep physics of the problems, this step directs them to explicitly state the physics concepts and principles that are relevant to the physical process being described.

This step is mirrored in the “Assess the problem” step of Teodorescu’s ACCESS strategy. While it is not explicitly directed in Heller’s CGPS strategy worksheets, selection of the relevant physics is a key feature of the Problem Solving Rubric used to mark the context-rich problems in Minnesota [40] and so is certainly implicitly emphasized and reinforced.

2.4.4.3 Step 3 & 4: Create a Physics Model

In order to reinforce the connections between physics and the real world students are asked to explicitly lay out their translation from a description of a realistic situation to a mathematical model. They are explicitly prompted to create a diagram, as well as to identify which assumptions are needed in order to proceed with their solution.

By explicitly prompting (and emphasizing via the marking rubric) both the drawing and the assumptions, we hoped to reinforce the importance of recognizing the limits and capabilities of the simple equations used in introductory physics, as well as encourage students to see these problems as mathematically corresponding to physical situations. We also intended to draw students’ attention to the key position that model construction holds in solving complex problems.
Several other problem-solving schemes also explicitly require this type of preparation for solution. This step is mirrored by the ACCESS protocol’s “Create a Drawing” step, which explicitly prompts for sketches or specific graphical representations such as a free-body diagram or chronological diagram. Similarly, the Minnesota CGPS method encourages students to “represent the problem in physics terms” and explicitly prompts creation of graphical representations such as vector or free-body diagrams. These aspects are assessed by Docktor’s problem solving rubric under the headings Useful Description and Specific Application of Physics.

The SCALE-UP GOAL problem-solving method (and Polya’s after which GOAL is modeled) also encourages students to make a drawing and summarize relevant information [41,42]. However we were concerned that these strategies present the modeling step as only summarizing the quantitative information necessary for a calculation, rather than constituting an important qualitative reasoning tool in its own right. Expert physicists commonly use diagrams to monitor and check their solutions-in-progress, and we hoped to demonstrate the value of these diagrams and to have students to practice developing them. These strategies also do not emphasize the importance of making simplifying assumptions, something that we felt was essential for tackling real-world problems.

The information requested in these steps together with the physics principles used in the previous step corresponds to Hestenes’ description of a mathematical model [43,44]. While this use of the term “model” is not as broad as that implied by the Modeling Instruction curriculum, we similarly expect to send the message that even though physics calculations may contain a number of assumptions or imperfections, they nevertheless rest on generalizable quantifiable principles that can give useful information about complex real-world situations.
2.4.4.4 Step 5: Solve the Problem

This step is the most commonly cited in each of the structured problem-solving methods in the PER literature, and is often the step that novice students try to start at.

In this step we direct the students to make use of the information in their model and the relevant physics they had previously identified in order to solve for the goal variable. Beichner’s GOAL strategy similarly directs students to analyze the problem by selecting relevant equations to solve for the unknown variable.

2.4.4.5 Step 6: Error-Checking and Sensemaking

In this step the students are prompted to reconsider their answer in terms of their everyday knowledge and to compare it to any quantitative benchmarks that they may happen to know.

Novices are often over-confident in their answers and decline to scrutinize or question them. This step explicitly directs them to use their commonsense to evaluate the answer, as well as to connect it back to the purpose or consequences of the original question. We expected that this reflection would help students to see the real-world connections in physics.

We deliberately used the term error-checking AND sensemaking here to signal to students that these are two different activities. Students focused on getting the right answer will often stop at error-checking. However, a solution free of algebraic errors can still be wrong and lead to the wrong conclusions if it is based on faulty assumptions. We tried to highlight sensemaking as the process of double-checking the meaning of the real-world context and the mathematical results.

A similar direction instructing students to reflect on the reasonableness of their result is a part of nearly every published problem-solving strategy. However, these strategies vary in their focus, with some placing much greater emphasis on broader metacognitive questions about the students’ strategies and
learning during the solution. The Minnesota CGPS strategy directs students to check their solution with their prompts for completeness, correct units, and reasonable magnitudes, procedures which focus primarily on the problem itself. The ACCESS protocol directs students to “Scrutinize your results” with an additional direction to “Compare the situation presented in the problem with a real-world situation,” similar to our instruction for students to make use of real-world benchmarks.

Polya and the GOAL strategy both instruct students to “look back” over their solution to see if it meets their expectations and “makes sense”. The GOAL strategy also asks more far-reaching questions, prompting students to consider this problem in the context of others in the course, to try to figure out why it was assigned, and to examine what was learned from doing it. Our strategy lacks this explicit metacognitive direction.

### 2.4.4.6 Complete Physics 100 Problem Solving Strategy

The complete Physics 100 problem-solving strategy is listed below. Table 2 lists the titles of the problem-solving steps that were used in lecture and recitation. Table 3 lists the full prompts that were printed on the recitation worksheets.

<table>
<thead>
<tr>
<th>Step</th>
<th>Step Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Interpret the Problem</td>
</tr>
<tr>
<td>2</td>
<td>Identify Relevant Physics</td>
</tr>
<tr>
<td>3</td>
<td>Model: Define Assumptions and Relationships</td>
</tr>
<tr>
<td>4</td>
<td>Model: Construct a Diagram</td>
</tr>
<tr>
<td>5</td>
<td>Solve the Problem</td>
</tr>
<tr>
<td>6</td>
<td>Error-Checking and Sensemaking</td>
</tr>
</tbody>
</table>

*Table 2: Summary of the structured problem-solving strategy used in Physics 100. These are the titles of the problem-solving steps that were used in lecture and recitation.*
<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1.   | **Interpret the problem**  
  - Carefully read and visualize the events described in the problem  
  - If necessary, sketch a picture to clarify sizes, directions and spatial relationships  
  - Clearly state the GOAL of the problem: what do you need to calculate and/or compare |
| 2.   | **Identify the relevant Physics Concepts**  
  - List briefly the major physical principles that are relevant to this situation. (e.g. conservation of energy, Newton’s second law, 1-D kinematics with constant acceleration, etc.) |
| 3.   | **Model: Define Physics Assumptions and Relationships**  
  - Using words and formulas as appropriate, interpret how the situation affects the physics variables defined in step 3b. Be sure to state all:  
    - Limitations or constraints on the physical variables (e.g. v < 0)  
    - Relationships between the physical variables (e.g. a₁ = a₂)  
    - Simplifying assumptions (i.e. friction negligible, massless rope, constant acceleration etc.)  
    - Initial conditions (i.e. Vᵢ = 0, aᵢ = -g) |
| 4.   | **Model: Make a Diagram and Summarize the Relevant Information**  
  - Write down a description that summarizes all of the relevant information in the problem statement in a clear way. This could include pictures, equations, or descriptions, or any of the following, where appropriate:  
    a. A statement of known and unknown quantities, with appropriate symbols defined  
    b. Any intuitions or expectations about the answer. (e.g. “because of the situation in this problem, I would expect the speed of car B to be only a little bit faster than that of car A”)  
    - A specific physics diagram (free-body diagram, energy bar chart, motion diagram etc.)  
    - A coordinate system that specifies the reference and direction of measurement for any spatial variables. (e.g. “x = 0 is the tabletop, positive x is down” or equivalent symbols) |
| 5.   | **Solve the Problem**  
  - Show all calculations |
| 6.   | **Check Your Answer (Error Checking / Sensemaking)**  
  - Demonstrate that your result has the correct units  
  - Compare results to known benchmarks  
  - If necessary, perform additional calculations to check your answer is sensible |

*Table 3: Detail of the structured problem-solving strategy used in Physics 100. These are the prompts that were written on the recitation worksheets completed by the students.*
The detailed prompts depicted in Table 3 have several elaborating statements below them explaining the required information for each step. For the first context-rich recitation in Physics 100, these prompts appeared as depicted, including the full elaboration. After the students had completed two context-rich recitations the italicized text was removed and only the titles of each step remained. Other than this change, the text of each prompt was the same from one recitation to the next, although the order of steps 3 and 4 was sometimes varied depending on the situation.

2.4.4.7 On the Lack of a Planning Step

The CGPS and ACCESS strategies explicitly direct students to plan their solution, and then the Solve step is framed in terms of executing their plan. These recommendations are based on research suggesting that novices are less likely to explicitly plan a problem solution. An explicit step directing students to plan their solution was originally included as an explicit part of our problem-solving strategy, but was cut after the first two years of implementation.

The main reason for cutting this step was lack of buy-in from the students. Informal observations of students in the recitations corroborated TAs’ reports that students would typically solve the problem and then return to fill in the plan step later, thereby evading any benefit gained from pre-planning. Despite repeated encouragements, most students never authentically attempted to plan their solution.

There are several possible explanations for this. One important possibility is students’ motivation to maximize their grade. Students often feel time-pressured during the recitation sessions, and despite the fact that this step was explicitly encouraged and rewarded with marks, students may have felt that the most efficient way to get as many marks as possible is to solve the problem before developing a plan. This “solve first, plan later” strategy enabled students to start with the physics strategies that they were more familiar with from high school: pattern-matching equations and variables and working through an algebraic solution.
In fact this may have been the optimal strategy for our recitation problems. It was very difficult to build problems that were difficult enough that they required forethought and planning without making them so difficult that some students would be unable to complete them. Another concern was that the problems would seem so difficult on first glance that students would feel that they didn’t know how to get started on the problems. Despite the fact that the structured problem-solving method is designed to help students work through problems they have no immediate idea how to solve, we were concerned that students would become daunted and refuse to meaningfully engage in a problem that they felt is too hard for them. In the interest of making the problems accessible to the extremely diverse student population of Physics 100, we may have erred on the side of making the problems too easy, which would make it possible to solve them without a planning step.

Another possible reason for students’ failure to adopt the planning step of our problem-solving strategy was insufficient support from the course TAs. Many TAs expressed skepticism about this step, and weren’t trained sufficiently on the motivation for including this step in the recitations. Without a firm understanding of why it was included, TAs could only justify this step to students as a rote part of the required process. This lack of a clear vision of how this step is helpful to the overall process made it just an arbitrary hoop to jump through and students treated it accordingly by performing it in haste right at the end of the recitation session.

Finally, observations in lecture showed that course faculty rarely demonstrated an explicit planning step before solving example problems, further reinforcing the idea that this step was unnecessary. Therefore, after two years it was dropped from our problem-solving method.

2.4.4.8 Scoring

The recitation grades were assessed with a set of rubrics that assessed students’ performance in each of the problem-solving steps. Rubrics are descriptive scoring schemes that contain a description of different levels of
performance on each of the steps, including the “perfect” level. These rubrics aid the TAs in grading the recitation problems and are also designed to aid the students in self-assessing their performance and interpreting the feedback given by TAs. Formative feedback has been demonstrated as effective at producing learning gains [45,46].

Our problem-solving rubric was based directly on the Docktor rubric used in Minnesota’s CGPS [40]. However, a few changes were made in order to enforce students’ participation in each step of the problem-solving strategy. Firstly, we gave students equal points for each step of the problem-solving strategy, clearly sending the message that every step of the process is important. Also, because we require students to fill something in for each step of the problem-solving strategy we always scored each step individually rather than allowing the students to demonstrate implicitly that they had done a step correctly by their work on other steps (as Docktor’s rubric does). The course instructors also felt that this one-to-one correspondence between the problem solving steps and assessment rubrics would be easier for the students and TAs to understand and therefore lead to more meaningful feedback and more consistent marking among the TAs.

As with many other aspects of the course, this rubric evolved over the first three years of implementation based on student and TA feedback. The figure below shows our rubric from the third year of implementation.
<table>
<thead>
<tr>
<th>Rubric Mark</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar to a grade of</td>
<td>&gt;80%</td>
<td>~75%</td>
<td>~50%</td>
<td>~30%</td>
<td>&lt;30%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1. Interpret the Problem</th>
<th>Problem summary and goal statement is appropriate, useful, and complete</th>
<th>Problem summary and goal contains minor omissions or errors</th>
<th>Parts of the problem summary and goal are missing or erroneous</th>
<th>Most of the problem summary and goal is erroneous</th>
<th>All of the problem summary and goal is erroneous</th>
<th>No attempt is made to summarize and identify the problem goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Identify Relevant Physics Concepts</td>
<td>The relevant physics is identified according to correct physics principles and concepts</td>
<td>The relevant physics is identified according to correct physics principles and concepts, with minor omissions or errors</td>
<td>The relevant physics is identified correctly but according to specific formulas or concepts rather than general principles</td>
<td>Identification of the relevant physics is mostly missing or inappropriate</td>
<td>The relevant physics is assessed incorrectly, or is entirely described in terms of surface features of the problem</td>
<td>No attempt is made to identify the relevant physics</td>
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<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
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</tr>
<tr>
<td>3. Model: Define Assumptions and Relationships</td>
<td>All defined assumptions and relationships are appropriate, useful, and complete</td>
<td>Assumptions and relationships have minor omissions, errors, or irrelevant statements</td>
<td>Parts of the assumptions and relationships are missing, irrelevant, or erroneous.</td>
<td>Most of the assumptions and relationships are missing, irrelevant, or erroneous.</td>
<td>All of the assumptions and relationships are missing, irrelevant, or erroneous.</td>
<td>No relevant assumptions or relationships are listed</td>
</tr>
<tr>
<td>---------------------------</td>
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<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>4. Diagram: Diagram and Relevant Information</td>
<td>The physics model is useful, complete, and appropriate.</td>
<td>The physics model has only minor omissions or errors</td>
<td>The physics model has major omissions or errors</td>
<td>The physics model is mostly erroneous or inappropriate</td>
<td>The physics model is completely inappropriate or erroneous</td>
<td>No attempt is made to construct a physics model</td>
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<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>5. Solve the Problem</td>
<td>The problem solution is appropriate and complete, with symbolic equations until the last step</td>
<td>The problem solution is appropriate and complete, with symbolic equations until the last step, with minor omissions or errors</td>
<td>The problem solution contains some good equations, but some equations are missing or inappropriate</td>
<td>The solution contains mostly wrong equations or solely numerical equations.</td>
<td>The solution contains completely wrong equations or solely numerical equations. No attempt to solve the problem symbolically is made</td>
<td>No solution is attempted</td>
</tr>
<tr>
<td>---------------------------</td>
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<td>-------------------------------------------------</td>
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<td>-------------------------------------------------</td>
</tr>
<tr>
<td>6. Check your Answer</td>
<td>The check of answer units and magnitude is appropriate and complete. Answer is compared to known values and units are explicitly checked</td>
<td>Check of answer units and magnitudes contains minor omissions or errors.</td>
<td>Check of answer units and magnitudes contains major omissions or errors. Either the explicit check of units or comparison to known values is missing</td>
<td>Check of answer units and magnitudes is mostly incorrect or missing.</td>
<td>The check of answer is vague or irrelevant. E.g. &quot;seems reasonable&quot;</td>
<td>No check of the answer is attempted</td>
</tr>
</tbody>
</table>

Table 4: Marking rubric used for Physics 100 recitation problems.

2.4.5 Changes to Recitations

The following sections describe the changes made to the Physics 100 recitations as a part of the course transformation. Because data-gathering for my major research project that was conducted in the recitation context occurred in 2009 (the third year...
of the transformation) these descriptions focus on the version of the recitations in that year.

During that year there were nine recitations:

Tutorials 1-5 were workshops focused on teaching students individual problem-solving skills. See section 2.5.4.3 below for a description of these.

Tutorial 6 was a Jeopardy Question [47], which is not discussed in detail in this document.

Tutorials 7, 8, and 9 were context-rich recitations. See section 2.4.5.1 for a description, and chapter 6 for the research conducted on these recitations.

All of the problems used in the 2007 and 2009 year of Physics 100 are reproduced in Appendix A.

2.4.5.1 Context-Rich Recitations

The instructors felt that standard end-of-chapter textbook problems helped the students gain facility with algebraic manipulation and pattern matching, but they often failed to advance students’ understandings of the “real physics” of the problems that they were doing. This finding has been echoed by research showing that ability to solve standard problems does not necessarily equate to conceptual understanding [39]. In order to meet their goal of teaching students how to apply physics knowledge to real-world situations other types of learning tasks would be required. context-rich problems were chosen for the course based on their claim to improve student problem-solving on novel problems [1].

These problems are organized around quantitative calculations, but are set in real-world contexts and often contain rich description and extraneous information, much like a real-world setting. They may also require students to make assumptions about quantities or relationships based on their knowledge of the problem context. In emphasizing the role of assumptions in application of
physics, we agree with Fortus [48], who has researched and argues for the need to teach students to make assumptions in introductory college physics.

Overall, the main reasons we chose context-rich problems to be the basis for the Physics 100 recitations are:

1. They fit with our goal of using realistic contexts to demonstrate situations where physics is relevant to the real world.

2. We felt they would give students the opportunity to develop the broad variety of skills required to model a realistic situation and interpret the situation.

3. This style of problem makes good use of the TAs. Having students solve challenging problems during sessions where the TAs are present creates opportunities for the students to learn from the TAs.

4. Using challenging problems for group work has been shown to increase students’ interactions with each other, creating more opportunities for students to learn from each other.

2.4.5.2 Group Structure and Roles

As suggested, these problems were given to the students in groups. Course logistics prevented the use of the recommended three-student groups, so students were put into groups of four.

We implemented Heller et al.’s suggested system of rotating group roles. In this system, students are assigned a particular role each week, such as Group Manager, responsible for proposing ideas and keeping the group moving forward; Skeptic, responsible for challenging the Group Manager’s ideas to make sure they are correct; or Recorder, who helps to facilitate group consensus and records the results. Because we were working with 4 students per group, we created a fourth role, the Explainer, who was responsible for explaining new ideas to other team members and to the TA. At the beginning of term we gave students an explanation of the importance and function of each
role. As recommended by Beichner and Saul [49], we endeavored to ensure that the groups were heterogeneous in ability (based on previous grades in physics and math) and that females were not in the minority of a particular group. We also shuffled the groups several times throughout the term, reassigning group members randomly while still following the above guidelines.

In the first year of implementation students expressed a significant amount of negative feedback about these externally-imposed group restrictions. The changing of groups in particular was met with significant resistance. Because the assigned groups were also used for the end-of-term Research Project (see section 2.4.7 below) students also complained of difficulties in coordinating out-of-class times to meet with their group to work on this project. Because UBC serves a geographically diverse student population with more than 50% of students commuting 30 minutes or more to campus, this was a significant challenge for students in scheduling meeting times and locations [50].

In addition, TA feedback and observations of students during the recitation sessions suggested that students did not take the group roles seriously, and would often just write down their roles that were required that week at the end of the recitation, having paid little or no attention to their assigned role during the recitation itself.

In order to address these problems, we experimented with different versions of the group structuring rules. The major study of student behavior during the recitations was conducted in 2009. In this year, we were still advocating and requiring students to use rotating group roles and were assigning groups at the beginning of term, but did not shuffle the groups during the term. We also asked students to report on locations that were convenient for them to meet and tried to create groups that were geographically overlapping with each other.

2.4.5.3 Workshops for Introducing Problem-Solving Skills

Performing a full analysis of a novel complex problem requires many steps and correspondingly varied skills. Students entering Physics 100 may not be
able to perform all of the separate tasks required to solve a complex problem. Indeed, the first years after the course transformation we found that the learning curve for tackling context-rich problems was too steep. Students were immediately overwhelmed by problems that they did not immediately know how to solve, and the structured problem-solving method for approaching these problems was not helpful because it was entirely new to the students. We realized that skills for performing the individual steps of the strategy needed to be learned as well. For example, students that have only solved traditional end-of-chapter problems have never needed to determine which physics is necessary to solve a problem: it is always the physics contained in the chapter immediately preceding the problem. Similarly, most students do not have practice in making assumptions in order to flesh out their physics model.

To enable the students to develop the individual skills necessary to address novel complex problems we decided to construct the recitations as a “skills progression”, similar to that advocated by Teodorescu [20]. Van Heuvelen [21] also recommends that we should “provide students with explicit instruction in the individual skills used by experienced physicists when solving complex problems and then help them combine these skills to solve complex problems.”

Based on these recommendations and the feedback on students’ initial difficulty with the full problem-solving method, we structured the first five recitation sessions as workshops focusing on one or two steps of the problem-solving method. The goals for each workshop were to give students some practice with performing those steps of the method as well as to motivate why those steps were helpful for finding the right answers and developing understanding. They were typically formatted as a series of exercises where students could perform each step in isolation, bracketed with full-class discussions to talk about how and why to perform these steps. The course TAs were briefed on these workshops during the weekly TA meeting, and had a guide to help them structure these discussions. The topic of each workshop is
summarized in Table 5 below, and the handouts and TA guides are reproduced in Appendix A.

<table>
<thead>
<tr>
<th>Recitation #</th>
<th>Skills Focus</th>
<th>Problem-Solving Method Step</th>
<th>Content Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction to Structured Problem Solving Method.</td>
<td>All</td>
<td>n/a</td>
</tr>
<tr>
<td>2</td>
<td>The properties of Models and the role of Assumptions</td>
<td>3 &amp; 4</td>
<td>Basic Kinematics</td>
</tr>
<tr>
<td>3</td>
<td>Identifying the Problem Goal and Relevant / Irrelevant Information</td>
<td>1 &amp; 3</td>
<td>Conduction</td>
</tr>
<tr>
<td>4</td>
<td>Identifying Relevant Physics</td>
<td>2</td>
<td>Conduction and Radiation</td>
</tr>
<tr>
<td>5</td>
<td>Error-Checking and Sensemaking</td>
<td>6</td>
<td>Radiation and the Inverse Square Law</td>
</tr>
</tbody>
</table>

Table 5: Skill and content focus for the first five Physics 100 recitations. These recitations were structured as workshops on developing students’ skills for individual steps of the overall problem-solving method.

2.4.5.4 Everyday Context

Similar to other aspects of the course, the Physics 100 recitations were set in an everyday context as much as possible. For example, problems about thermal conductivity were set in the context of household freezers or home insulation. Problems about kinematics and energy were set in the context of everyday transportation: cars, cycling, and buses.

As mentioned earlier, this was done to encourage students to see physics as relevant to the real world but there was an added pedagogical goal as well. Because we hoped to expose some of the more subtle ways that assumptions and modeling can help to simplify and address the complexities of real-world situations, we needed the students to be able to make assumptions about the problem contexts. We assumed that setting the problems in an everyday world would enable the students to leverage their experience and intuition to develop models and to make sense of the physics.
Examination of this assumption is one of the key studies conducted in this thesis. This study is described in chapter 6.

2.4.5.5 Motivation for Calculation

Another important design feature of the Physics 100 recitations was that the circumstances of each problem were designed to motivate a true calculation, rather than a qualitative best guess. Interviews with students had shown us that students feel that everyday problem solving rarely involves calculations. Rather, they said that they would tend to make decisions intuitively. (see chapters 3 and 4 below for details of the interviews that informed this.)

In order to demonstrate that quantitative problem-solving is a realistic and useful skill, we tried to construct situations where a calculation was truly called for. In many cases that meant demonstrating ways in which physics calculations could save money or time. We also tried to show how physics calculations could be consequential to peoples’ health, for example in planning a search for a missing hiker.

In addition, an effort was made to make the result of the calculations consequential in that they would lead to a specific decision or action. This is in sharp contrast to many physics problems which give no reason for performing a calculation other than the question itself.

2.4.5.6 Two Versions of Each Tutorial

These everyday contexts were originally chosen by the instructional team. However, interviews after the first year of the course revealed that some students did not agree that the problem contexts were “everyday”. (See chapter 4 below for a detailed discussion of these interviews). For example, while all of the students were familiar with environments where the physics of home-heating is important, most of them have never paid a heating bill and were therefore not very interested in the details of household heat loss. Several students reported that this was relevant to the real world, but not to themselves.
Another student objected to a problem that was about an astronaut whose suit was made of a thin garbage bag, saying that this problem sent a message that physics was only good for fantastical situations.

This was an important comment, because initially several of our problems had been adapted directly from the University of Minnesota’s online archive for context-rich problems, many of which use an arbitrary or unrealistic motivation for calculation such as a “competition” or by stating that the student “wonders” what some quantity will be. For example, another of our problems in the first year was adapted directly from this archive and opened with the phrase “You are a stunt coordinator for a movie shooting in Vancouver.”

Based on students’ comments on these problems, I conjectured that students might react differently to a problem that was set in their everyday lives as they live them right now vs. a problem that was set in a hypothetical future job or situation. In order to investigate this possibility each recitation problem in the 2009 year came in two versions that were mathematically identical but had slightly different cover stories. The first version, which I called the Real Context, were problems set in the real world but which might not be strongly related to the students’ current lives or career goals. The second version, which I called Personal Context, endeavored to place the problems within the students’ everyday lives and to make the calculations consequential. The criteria for these two different types of problems are summarized on Table 6 below.
<table>
<thead>
<tr>
<th><strong>Personal Context</strong></th>
<th><strong>Real Context</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motivation</strong></td>
<td></td>
</tr>
<tr>
<td>Quantitative calculations are warranted. i.e. the extra effort to get a numerical result is worthwhile</td>
<td>Quantitative calculations may be asked in situations where commonsense estimation would be good enough</td>
</tr>
<tr>
<td>Results of calculations are consequential. There will be some decision made or behavior will be different as a result of the calculation</td>
<td>Calculations may be asked where no decision or action is implied by the result.</td>
</tr>
<tr>
<td><strong>Setting</strong></td>
<td></td>
</tr>
<tr>
<td>Setting is described in the first person. (i.e. “you”)</td>
<td>Setting is described in the first person, but focus of the problem may be “a friend”</td>
</tr>
<tr>
<td>Setting is drawn from everyday experiences that students are likely to have experienced</td>
<td>Setting may be an unusual circumstance (i.e. a contest, an experimental art work, a movie set)</td>
</tr>
<tr>
<td>Setting may be a future job that is close to the career goals of the population (i.e. doctor, biologist)</td>
<td>Setting may be a future job that is far from the career goals of the population (i.e. traffic consultant, engineer)</td>
</tr>
<tr>
<td>The calculated result is a quantity that the students are able to interpret in terms of their own experience. (i.e. length, mass, fuel efficiency)</td>
<td>Calculated result may be a physics quantity that students can only interpret in terms of other physics knowledge taught in the course (i.e. acceleration, intensity)</td>
</tr>
</tbody>
</table>

*Table 6: Criteria for personal context and real context tutorials. Each recitation problem in 2009 was developed in two versions with identical mathematical structure but slightly different cover stories.*

Students were split into two groups, each of which received one of these types of problems throughout the term. Observations of students’ response to the problem cover stories and analysis of the CLASS scores of the two groups of students did not show any significant difference between these groups. Because of the lack of result in initial investigations there is no further investigation of the impact of these contexts in the remainder of this dissertation.

### 2.4.5.7 Solutions as Worked Examples

To offer students the best chance of learning from the recitations we offered students solutions that were structured according to recommendations from the Worked Examples literature [51,52]. Solutions contained mathematical, pictorial, and descriptive representations presented in an integrated fashion to help demonstrate the meaning and reasons for the various decisions made as a
part of the solution. By providing these highly detailed solutions, we hoped to support students’ learning of expert-like problem-solving skills.

2.4.6 Changes to Lecture

Many of the major changes to the Physics 100 lectures have already been noted: the topics covered in the course were changed and new lecture materials were developed to support this; the examples and questions used in lecture were written in an everyday context wherever possible; and a structured problem-solving method was used for in-class example problems. The lecturers continued to use electronic response systems (clickers) to poll students with qualitative and quantitative questions during class. There were also explicit lectures on the goals of this course transformation and the various methods that were being implemented in order to support it.

The discussion on climate change was a significant deviation from the normal curriculum of an introductory course, but the style of presentation of this knowledge and the expectations for student learning followed a familiar pattern. Students were presented with diagrams representing physical phenomena and accompanying formulae, and these formulae were used to perform quantitative calculations.

However, some of the discussion on climate change was conducted in a new way: the class moved away from straightforward calculations based on simple models with given information, and discussed some of the challenges in the application of mathematical climate models to the Earth’s climate. These discussions were largely qualitative, and covered several important issues such as the role of feedback in climate change, the history of Earth’s climate, and the evidence for and against humanity’s role in inducing climate change. Several common arguments about the nature of climate change and humans’ role in it were presented and critiqued by the instructor. In addition, several common statements about climate change that have been recently debunked in the literature were presented as myths of climate change.

This material was not assessed on the course’s exams, but was intended to help students learn about the nature of scientific argumentation and critique. This was
intended to help prepare students for the group research project, which required them to critique a scientific argument. This research project is described in the next section.

2.4.7 Group Research Project

An important change to the course was the incorporation of a final project where students work in small groups to quantitatively model and estimate an answer to a scientific question and present their results to their peers. Students choose project topics from a list provided by instructors and which were drawn from a magazine article suggesting various actions to reduce energy and greenhouse gas use, and students were asked to quantify the impact of these actions [53]. For example, projects have addressed the energy and greenhouse gas savings from using LEDs for city lighting and the energy benefits of paying bills online rather than by paper mail. Suggested topics are limited to those that fell within the scope of students’ ability to research and understand the topic and students are free to choose topics that were relevant or that interested them. It was the intention of the course instructors that working on the final project would give students important practice in applying physics principles to real-world situations.

There was little explicit instruction on the final project built into the course. The final project assignment was introduced and explained to student groups during the weekly recitation session in week 7 of the course. Instructors provided an example project and the project marking rubric, which emphasizes explicit discussion of physics but does not explicitly require students to use sophisticated physics models. Initially, the project was assessed via final presentations conducted in weeks 12 and 13 of the course and were graded by the course TAs and one of the course instructors. However, due to logistical pressures the presentation format was changed to a poster session in subsequent years.
3 STUDY OF CHANGES IN STUDENTS’ BELIEFS ABOUT PHYSICS

One of the key goals of the transformation in Physics 100 was to improve the impact that the course had on students’ belief in the relevance of physics to the real world. As mentioned in section 2.2.4, previous results of the CLASS survey [14] conducted in Physics 100 had shown that students’ belief in the relevance of physics to the real world declined over the course of instruction.

In this study I use the results of the CLASS survey, which was conducted in 2006 prior to the transformation as well as in each year through 2010. I also supplement the information gleaned from the CLASS survey results with the perspective of the course instructors.

3.1 Goal and Research Question

The goal of this study is to examine the research question:

Did the changes to Physics 100 improve students' beliefs regarding the relevance of physics to the real world?

3.2 Methodology

The CLASS survey uses 42 statements about physics and learning with which the students are asked to agree or disagree on a 5-point Likert scale. Each statement has a clearly favourable and unfavorable response, as defined by the responses given by expert physicists and physics professors. Student responses are scored by determining the percentage of items for which the student has given a favourable response, termed the % favourable score. For example, if a physics expert would respond ‘strongly disagree’ to a particular item, both ‘strongly disagree’ and ‘disagree’ are considered favourable responses. The response scale is collapsed in this way to avoid implicitly treating a ‘strongly disagree’ response as worth two ‘agree’ responses. The % favourable score for a particular student can be calculated for both a pre- and post-test, which enables calculation of the % shift in a student’s favorable scores. Similar calculations can determine the pre, post, and shift in each students’ % of unfavorable scores.
The items on the survey are grouped into categories by the test developers based on a factor analysis which identifies groups of response items that tend to correlate with each other. For example, the items in the “Real-World Connections” category are listed in Table 7 below. Each item on the survey can appear in more than one category, although some items are not strongly correlated with any others and are therefore not included in any category. Such items are, however, included in the Overall scores.

<table>
<thead>
<tr>
<th>Question</th>
<th>CLASS Questions: Real-World Connections Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Learning physics changes my ideas about how the world works.</td>
</tr>
<tr>
<td>30</td>
<td>Reasoning skills used to understand physics can be helpful to me in my everyday life.</td>
</tr>
<tr>
<td>37</td>
<td>To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.</td>
</tr>
<tr>
<td>35</td>
<td>The subject of physics has little relation to what I experience in the real world.</td>
</tr>
</tbody>
</table>

Table 7: CLASS response items in the Real-World Connections category. These items are scored on a 5-point Likert scale: strongly agree, agree, neutral, disagree, and strongly disagree. Responses to items 28, 30, and 37 are considered favorable if the student chooses ‘strongly agree’ or ‘agree’. Responses to item 35 are considered favorable if the student chooses ‘strongly disagree’ or ‘disagree’.

The course instructors agreed that the four questions in the Real-World Connections category addressed one of the main goals in the course transformation: that students should see physics as relevant to themselves and to their lives. As such, improvement on this category was considered an important assessment of the success of the changes.

The CLASS survey was administered as a pre- and post-test in each year of Physics 100 starting in 2006. However in 2007 there was an important change in how students were recruited for the survey. In 2006 the survey was strictly voluntary, resulting in predictably low numbers of participants, but in 2007 through 2009 the survey was mandatory, with students awarded 1% participation credit for completing both the pre- and post-tests. This resulted in much higher participation rates as depicted in Table 8 below. The effect of this change in survey recruitment on the selection of survey participants is explored in section 3.5.1 below.
<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Students</th>
<th>Number of matched pre/post responses</th>
<th>Participation rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>717</td>
<td>91</td>
<td>13%</td>
</tr>
<tr>
<td>2007</td>
<td>711</td>
<td>384</td>
<td>54%</td>
</tr>
<tr>
<td>2008</td>
<td>708</td>
<td>481</td>
<td>68%</td>
</tr>
<tr>
<td>2009</td>
<td>811</td>
<td>506</td>
<td>62%</td>
</tr>
</tbody>
</table>

Table 8: Class sizes and participation rates for the CLASS survey in Physics 100 from 2006 to 2009. In 2006 participation in the survey was strictly voluntary. In 2007 through 2009 1% of course grade was given for participation in both the pre- and post-tests.

In all years, the survey was administered online via the course’s website.

### 3.3 CLASS Survey Results

The CLASS survey results for 2006 – 2010 are shown below. Because of variations in the incoming classes each year, I focus primarily on the shift scores, which identify how students’ responses changed over the course of the term. Each bar reports the average for the whole class, and the error bars show the standard error for each score. The main categories of interest were the Real-World Connections category and the Overall score, which are summarized on Figure 1 and 2 below.
Figure 1: Pre-post shift in favorable responses for the Overall and Real-World Connections categories on the CLASS survey. The shifts are calculated as $\%\text{shift} = \%\text{favorable\_post} - \%\text{favorable\_pre}$ for matched pairs of pre/post surveys.

Figure 2: Pre-post shift in unfavorable responses for the Overall and Real-World Connections categories on the CLASS survey. The shifts are calculated as $\%\text{shift} = \%\text{unfavorable\_post} - \%\text{unfavorable\_pre}$ for matched pairs of pre/post surveys.
An examination of all five years of data using ANOVA shows that there are some significant differences between the years. Pairwise Tukey Honest Squared Differences (HSD) comparison shows that the Favorable Overall score for 2009 is significantly lower than it was in 2008 (p<0.05), and the score in 2010 is significantly greater than it is for 2009 (p<0.01). Similarly, the Unfavorable Overall shifts for 2009 were greater than those in 2008 (p<0.05) and in 2010 (p<0.001). There were no significant differences between any other pair of years.

ANOVA analysis of the Real-World Connections scores showed no significant effect of the course year on either of the Favorable or Unfavorable scores (p>0.05).

Because the course transformation was explicitly intended to improve students’ perceptions of the relevance of physics to the real world, we were surprised to see no significant difference between the 2006 (pre-transformation) results and the 2007 (post-transformation) results. After the appearance of some improvement in the 2008 Real-World Connection results, we were also surprised to see the results for 2009 decrease and become comparable to the initial pre-transformation scores.

3.4 Analysis of Pre-Course Scores

One of the factors that I examined for connection to these surprising results was the variation in the incoming students’ survey scores. The pre-course scores for 2006 – 2010 are shown in Figures 3 and 4 below.
An ANOVA analysis revealed some significant differences in the pre-course scores between different years. For the Overall Favorable category, the pre-scores in the 2008 year are significantly lower than in the 2007 year (p<0.05). For the Overall Unfavorable category, the pre-scores in the 2007 year are significantly higher than in the 2008 year (p<0.05).
category the 2006 pre-scores are significantly higher than the 2007, 2009, and 2010 years (p<0.05). For the Real-World Connections Favorable category the 2007 and 2010 years are significantly higher than the 2006 and 2008 years (p<0.05). Finally, for the Real-World Connections Unfavorable Category, the 2006 and 2008 pre-scores were both higher than the 2010 score.

To investigate the influence of these variations in pre-score on the % shifts I examined the correlation between these variables. For the Overall category the correlation between shift and pre-scores is R=-0.40 and for the Real-World Connections scores it is R=-0.48, both of which are significant at the p<0.001 level. These correlations may be partly due to the floor effect: students who begin the course with low beliefs haven’t as much to lose on the post-test, and are therefore not capable of posting very large negative shift scores. Alternatively, one might imagine that students with low pre-scores are less likely to engage with the course in such a way that their personal beliefs about physics and learning might be challenged and thereby evolve. In either case, it is clear that students with higher pre-scores are more likely to have strong negative shifts.

To take the effect of these variations in pre-scores into account, I conducted a multivariable regression analysis to examine the CLASS shifts with the pre-scores and the course year as predictors. However, when the pre-scores were included in the model the course year was not determined to be a significant predictor of shifts, suggesting that the variation observed in section 3.3 above was largely due to changes in the pre-scores rather than in changes due to the course curriculum.

In the following sections I examine several other factors to investigate the surprising lack of improvement in the CLASS scores in the 2007 year and the surprising decrease in scores in the 2009 year.

3.5 Analysis of Lack of Change in 2007

In order to examine whether some other difference in the course could be contributing to these results, I examined several factors that could impact the CLASS scores.
3.5.1 Differences in Population due to Recruitment Method

Because of the difference in recruitment method and participation rates there was some concern that the student population participating in each year might represent different segments of the class. In particular, in 2006 the survey was voluntary and in 2007 it was made mandatory.

In order to assess the impact of the differing requirements for survey participation, I compared the course grades of the participating students to the overall average course grade for both 2006 and 2007. The surveyed sample’s average grade was 5% higher than the average grade of the entire class in 2006 and was 4% higher than the entire average grade of the entire class in 2007. Because the difference in average grades were so similar, I could not conclude from the course grades that a difference in sampled population could be responsible for the lack of significant change in the CLASS shift from 2006 to 2007.

3.5.2 Faculty Changes

Another important factor to consider in interpreting these results is the impact of the faculty changes from one year to the next. The course is taught in three different sections, and in the period studied a total of six different faculty taught in the course. As well, there were different participation rates in each of the course sections which weighted the results of that section more heavily and may have influenced the overall results. The number of participants in each section and the faculty teaching each section are illustrated in Table 9 below.

<table>
<thead>
<tr>
<th>Year</th>
<th>Section 101</th>
<th>Section 102</th>
<th>Section 103</th>
<th>Total</th>
<th>N (whole class)</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>27</td>
<td>36</td>
<td>28</td>
<td>91</td>
<td>717</td>
<td>Instructor A</td>
</tr>
<tr>
<td>2007</td>
<td>97</td>
<td>152</td>
<td>135</td>
<td>384</td>
<td>711</td>
<td>Instructor B</td>
</tr>
<tr>
<td>2008</td>
<td>145</td>
<td>138</td>
<td>198</td>
<td>481</td>
<td>809</td>
<td>Instructor C</td>
</tr>
<tr>
<td>2009</td>
<td>168</td>
<td>157</td>
<td>181</td>
<td>506</td>
<td>811</td>
<td>Instructor D</td>
</tr>
<tr>
<td>2010</td>
<td>137</td>
<td>102</td>
<td>116</td>
<td>355</td>
<td>734</td>
<td>Instructor E</td>
</tr>
</tbody>
</table>

Table 9: Instructor changes and number of CLASS survey participants in Physics 100 from 2006 to 2010.
To examine whether instructor effects might be responsible for the lack of improvement in the CLASS scores after the course transformation, I compared the 2006 and 2007 results using only the data from the instructors that taught both years. The results again show no significant difference between the 2006 and 2007 results. (See Figures 5 and 6 below)

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**Figure 5:** Pre-post shift in favorable responses for the Overall and Real-World Connections categories on the CLASS survey for the two sections that had the same instructor for 2006 and 2007.

**Figure 6:** Pre-post shift in unfavorable responses for the Overall and Real-World Connections categories on the CLASS survey for the two sections that had the same instructor for 2006 and 2007.
3.6 Analysis of Decline in 2009

Despite the appearance of some significant improvement in the 2008 Real-World Connection results, the results for 2009 and 2010 were comparable to the initial CLASS scores prior to the course transformation in 2006.

The change in the CLASS shifts was surprising and disappointing. The results were surprising because the course instructors had not endeavored to make any major changes in the 2009 year. While there were some refinements made to each of the lecture, lab, and recitation materials, the course instructors felt that on the whole the 2009 course was taught in the same way as the 2008 course. The CLASS shifts in 2009 were disappointing because the 2008 results were statistically significantly better than the 2007 results, and if the improvement demonstrated in 2008 had continued it would have been good evidence that the refinements to the course in 2007 had paid off and overall the course transformation had been successful.

To try to understand why the shifts in 2009 were not as favorable as in 2008 I investigated other possible factors that might explain the decline. I examined several possible explanations for these changes: the change of one course instructor from 2008-2009; changes in the demographic composition of the students in the course; and differences in timing of the post-course survey.

3.6.1 Instructor Changes

One possible cause was the change of instructor in one section of the course (see Table 9 above). To investigate the possibility that this one section was responsible for the major shift seen from 2008-2009 we looked at the CLASS results for only the two sections that had the same instructor for all three years. The results, summarized below in Figure 7 and 8 show that the 2009 results for both of these instructors were statistically indistinguishable or, in the case of the Overall favorable %shift, worse than their 2007 results. Because the pattern of declining results in 2009 occurred even in the two sections that had the same instructor, I rejected the hypothesis that the decline was caused by the new instructor.
Figure 7: Pre-post shift in favorable responses for the Overall and Real-World Connections categories on the CLASS survey for the sections that had the same instructor each year.

Figure 8: Pre-post shift in unfavorable responses for the CLASS survey Overall and Real-World Connections categories for the sections that had the same instructor each year.
3.6.2 Student Demographics

The observed variation in CLASS pre-scores suggested that there might have been an important difference in the student population that year that could explain the decreased CLASS shifts. I investigated the hypothesis that perhaps there had been a significant change in the demographics of the students taking the course in the 2008 year that could help to explain the difference.

While there are correlations between students’ program and their Overall CLASS shifts, a linear model of the CLASS scores that takes students’ program, section, and the course year into account does not find that these demographic factors are significant predictors of students’ CLASS scores. Therefore, I could not conclude that the demographic differences in the student population in 2009 were responsible for the CLASS shifts.

3.6.3 Timing differences

Because we were concerned that the scores on attitude and conceptual surveys could be influenced by their timing in the term we intended to always give the survey during the first week of class and the last week before the final exam. However in 2009 due to logistical errors it was necessary to leave the post-survey open for two full weeks. In order to investigate the possibility of the extended post-testing period affecting the shift results I compared the CLASS scores for the participants that completed the post-test in the first week of the testing period against the scores for the participants that completed it in the second week of the testing period. These comparisons are depicted in figures 7 and 8 below.
Figure 9: Favorable CLASS shift results for the 2009 year, broken down by the week in which students completed their post-test. In this year, the post-testing period was open for two weeks, instead of the usual one week.

Figure 10: Unfavorable CLASS shift results for the 2009 year, broken down by the week in which students completed their post-test. In this year, the post-testing period was open for two weeks, instead of the usual one week.

Because there was no statistical difference in the category scores of the two groups we concluded that this effect could not be responsible for the different CLASS shifts between 2008 and 2009. Therefore the differences in timing of the post-test were discarded as a possible explanation for the decreased CLASS shifts in 2009.
3.7 Summary

According to my analysis, the CLASS shift in the Overall and Real-World Connections category did not significantly improve over the years 2006 – 2010 and on average remained negative in both categories, indicating that students’ beliefs and attitudes towards physics were less favorable after taking the course. Investigations to examine the effect of changes in faculty, different recruiting methods for the CLASS survey, changes in student demographics, and changes in the timing of the post-test did not find that any of these factors explained this result. The results of this survey suggest that presenting physics in an everyday context is not sufficient to promote students’ perception of the relevance of physics to the real world.
4 Exploratory Post-Course Interviews

In order to investigate students’ overall perceptions of the course changes and to explore their impact on student’s attitudes towards the real-world relevance of physics nine students were interviewed after the completion of the first year of the transformed Physics 100 course in 2007. This study used CLASS statements as interview prompts to examine students’ perceptions of the relevance of physics to the real world in detail. Based on their responses, I identify several ways in which students perceive the relevance of physics to the real world and factors that promote or inhibit the perception of relevance. One key finding was that students judge relevance according to their immediate circumstances and career goals, and therefore problems that relate to implausible or hypothetical future situations may not be seen as relevant.

4.1 Goal and Research Questions

These interviews had several goals. Firstly, because we were using the CLASS survey as a measure of the course’s impact on students’ perception of the real-world relevance of physics, I wanted to probe the details of how students interpreted the wording of the CLASS questions. Even though students’ interpretation of these questions had been validated by the survey’s original authors [54] I wanted to re-validate using our local population. Therefore I address the research question:

1. How do students interpret the CLASS survey questions?

Secondly, I wanted to inquire about students’ overall impressions of how the Physics 100 course affected their perception of the relevance of physics to the real world. Through general conversation about the course, I hoped to uncover the ways that students see physics as being connected to the real world, and explore the factors they cite as affecting their beliefs. This goal motivates the next two research questions:

2. In what ways do students see physics as related to the real world?

3. What factors do students cite as affecting their belief in the relevance of physics to the real world?
Finally, I wanted to obtain general feedback on the course elements that would help us to develop subsequent versions of the course. Although this was an important goal of these interviews, it is not relevant to the research questions addressed in this thesis, so I will not focus on the information gleaned in this regard.

As described in Table 1, the research questions mentioned above offer a perspective on the overall dissertation research questions.

4.2 Selection of Participants

Because I wanted to gather a representative sample of students’ impressions of the course I attempted to recruit an interview cohort that would span the variety of student responses towards the course on the CLASS instrument. Therefore, participants who had extremely high or extremely low shifts in scores on the CLASS Overall and Real-World Connections categories during the 2007 year were invited to participate. Participants were contacted by email, and all students that volunteered were invited into the study.

Because the intent of the interviews was merely to probe the variety of student attitudes and suggest possible reasons for shifts on the CLASS scores, it was deemed unnecessary to have a demographically representative sample. All nine of the participants were female. Six of the nine participants were life sciences majors, which approximately matches the course demographics for that year.

4.3 Interview Protocol

The protocol used was a semi-structured conversation using CLASS statements as prompts. I began each interview with a few demographic and background questions, and tried to establish a nonjudgmental rapport with the participant. Then I proceeded to read out individual CLASS questions and ask the students to indicate their agreement on the standard Likert scale of Strongly Agree, Agree, Neutral, Disagree, or Strongly Disagree. Sometimes students would make a choice on this scale, but often they would spontaneously comment on the question or the subtleties of their opinion. Before proceeding to the next question I always asked students to provide their response to the current item.
In this manner, each student was interviewed on all four of the CLASS Real-World Connections questions and some of the Problem-Solving questions. Due to time restrictions, not every question was asked of every student. The questions in this protocol are summarized in Table 10 below. As a novice interviewer I was concerned that using free-form follow-up questions would unduly bias the participants’ responses, so I used a rigid set of follow-up questions to probe students’ reasons for their CLASS item responses. These follow-up questions are listed in the complete interview protocol in Appendix B.
<table>
<thead>
<tr>
<th>Demographics Questions</th>
<th>CLASS Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>How old are you?</td>
<td></td>
</tr>
<tr>
<td>What is your major in school?</td>
<td></td>
</tr>
<tr>
<td>Can you tell me a little about why you chose that major?</td>
<td></td>
</tr>
<tr>
<td>What year are you in?</td>
<td></td>
</tr>
<tr>
<td>What is your favorite class? Why?</td>
<td></td>
</tr>
<tr>
<td>What do you want to do when you graduate?</td>
<td></td>
</tr>
<tr>
<td>Why did you volunteer for this study?</td>
<td></td>
</tr>
</tbody>
</table>

**CLASS Questions: Real-World Connections Category**

“I’ll read these statements to you, and I’d like you to reply by letting me know whether you agree or disagree with them on a scale of 1 to 5, 1 being strongly agree, and 5 being strongly disagree.”

<table>
<thead>
<tr>
<th>Statement</th>
<th>Likert Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning physics changes my ideas about how the world works.</td>
<td>28</td>
</tr>
<tr>
<td>Reasoning skills used to understand physics can be helpful to me in my everyday life.</td>
<td>30</td>
</tr>
<tr>
<td>To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.</td>
<td>37</td>
</tr>
<tr>
<td>The subject of physics has little relation to what I experience in the real world.</td>
<td>35*</td>
</tr>
</tbody>
</table>

**CLASS Questions: Problem-Solving Category**

“I’ll read these statements to you, and I’d like you to reply by letting me know whether you agree or disagree with them on a scale of 1 to 5, 1 being strongly agree, and 5 being strongly disagree.”

<table>
<thead>
<tr>
<th>Statement</th>
<th>Likert Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.</td>
<td>13*</td>
</tr>
<tr>
<td>If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.</td>
<td>15</td>
</tr>
<tr>
<td>Nearly everyone is capable of understanding physics if they work at it.</td>
<td>16</td>
</tr>
<tr>
<td>I can usually figure out a way to solve physics problems.</td>
<td>34</td>
</tr>
<tr>
<td>When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.</td>
<td>42</td>
</tr>
<tr>
<td>After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic</td>
<td>5*</td>
</tr>
<tr>
<td>If I don’t remember a particular equation need to solve a problem on an exam, there’s nothing much I can do (legally!) to come up with it.</td>
<td>21*</td>
</tr>
<tr>
<td>If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.</td>
<td>22*</td>
</tr>
</tbody>
</table>

**Table 10:** Summary of questions in exploratory post-course interviews. Students were asked to read these questions aloud, comment on whether they agreed or disagreed with them on a 5-point Likert scale, and asked to explain their reasons for their responses. Responses to questions with a * next to the item number are considered favorable if the student disagrees with the statements.
4.4 A Methodological Comment

In order to check the validity of these interviews, the students’ verbal responses to the CLASS questions were compared to their actual responses on the CLASS survey. A good match between the students’ CLASS post survey responses and their responses in the interview would support the idea that:

1. The students’ responses on the CLASS survey were stable from the time they took the post survey until the time they were interviewed (approximately 3 months) and

2. The students’ responses in the interview context draw upon the same attitudes and opinions as their responses in the survey.

A comparison of the CLASS post scores and responses given in the interview reveals that these match only 57% of the time. For the purposes of this comparison, a response of “Strongly Agree” is considered a match with the response “Agree” and similarly “Strongly Disagree” and “Disagree” are considered a match. This agreement rate is better than chance, but still indicates that either or both of condition 1 and condition 2 above are not met.

Either of these conditions might plausibly be violated. As a novice interviewer, I may have failed to create the framing of “mutual enquiry” recommended for this type of clinical interview [55] and the students may have been framing these interviews as evaluative tests. In addition, it is reasonable to propose that during the delay between the CLASS post-test and the interviews that these students’ attitudes towards physics legitimately changed. Many of them were enrolled in another physics course, which could certainly affect their perspectives. We must consider the possibility these CLASS questions do not measure a students’ attitude as a unitary and stable property. Students are humans, and as such are sensitive to priming effects and liable to answer the same question differently on different days.

This suggests that we should not draw conclusions from these interviews about the reasons for the particular responses of these particular students on their CLASS post-test. However we can take these students as representatives of their classmates, and treat their responses as representative of viewpoints that may arise in the population at large.
4.5 Interview Results

The principal results of these interviews are an illustration of the diverse ways in which students conceive of the notion of “real-world connections” and of the notion of “reasoning skills used in physics.” As well, students gave us some specific feedback on their impressions of what constitutes a real world context that informed future development of the course and the recitations.

4.5.1 Diverse Interpretation of “Reasoning Skills Used to Understand Physics”

Students expressed a wide diversity of interpretations of the phrase “reasoning skills used to understand physics”, used in CLASS question 30. This variety of interpretations reveals students’ different expectations about the nature of physics reasoning skills, as well as their implicit epistemological stance on the potential connections between physics and the real world.

In the following sections I will give examples of several different ways that students interpreted the concept of “reasoning skills used to understand physics” and illustrate each example with an excerpt from the interviews.

4.5.1.1 Reasoning Skills as Problem Solving

Several students’ answers reflected their interpretation that “reasoning skills used to understand physics” are a form of critical thinking, problem-solving skills, or the specific problem-solving strategy used in the Physics 100 recitations.

One student mentioned applying mathematics to word problems as well as critical thinking, which he describes as being distinct from specific physics content knowledge.

Alberto: With physics problems you’re generally taking words and applying some kind of math to them.

Interviewer: Do you find those skills useful to you...

Alberto: I’m just thinking if they’re useful...I think they help like problem-solving skills in general, they are good skills to practice.
*Interviewer:* Why?

*Alberto:* Well in order to be a successful person you need to be able to critically think and I think that's the main thing they try to teach at the university. You're not going to remember facts, and you're not going to remember physics formulas.

The second student cites reasoning skills as being related to looking logically at questions posed in class, and making good use of formulae.

*Interviewer:* (prompting for agreement / disagreement) “Reasoning skills used to understand physics can be helpful to me in my everyday life.”

*Joyce:* The first thing that comes up is like problem-solving skills and just like when you look at a question, the logic of it, and that's useful in other classes. I'm not sure if you'd consider that everyday life. It's certainly my everyday life. [...] Like math or even other courses like biology when you're given a statistical analysis of something. Population density or something like that. So yes. problem-solving skills.

*Interviewer:* [...] Do you think that you developed those reasoning skills over the course of Physics 100 or do you think you mostly have the same before and after taking the course?

*Joyce:* Well for physics it's applying the question logically to like a formula. At least for that course it kind of is. And so a lot of courses you're applying it to a formula. I'm learning physical chemistry right now and that's pretty much the same kind of idea.

An interesting aspect of the above response is that she interprets “everyday life” to mean “other courses at school”. This seems quite a sensible interpretation for a student that, like most other undergraduates, spends most of her time engaged in school-related activities. It also seems that she is using Physics class as a standpoint from which to refer to her other courses.

The third student interprets reasoning skills as a process or strategy used to solve problems.

*Interviewer:* Reasoning skills used to understand physics can be helpful to me in my everyday life.
Leslie: Yes.

Interviewer: Why do you say that?

Leslie: Well I guess there are two aspects of that. There’s the actual mental or psychological, what ever you want to use, process of solving problems. So it kind of develops your ability to not just narrowly look at one idea, but to see all the aspects bring together what the, know which aspect you need to take into account. Some you need to disregard and some you have to, and then follow kind of a logical process to get your results. [Continued below]

4.5.1.2 Reasoning Skills as Physics Content

Leslie, the student quoted above, also mentioned the relevance of physics content knowledge to other sciences.

Leslie: [Continued from above] Then there's also the physics side. What we're being taught. It's already very clear that it's applicable in our normal life, just that we need, each field needs to recognize that it's applicable [...] if you have biology students in there and they aren't connecting to what's being taught. They might not see that connection and, I dunno, I guess I'm a huge interdisciplinary person. And same with chemistry and all that. I don't see how physics can be left out of any science I guess is what I'm saying. It's one of those fundamental skills that needs to address each portion. If it's being taught well rounded with all the aspects, then you should be able to use it in anything. If a teacher in a biology class asks a question about bird flight, you should draw from your physics course and say how is this going to work.

In this quote, Leslie specifically highlights that she believes that physics is a “fundamental skill” that offers knowledge that is useful in other scientific disciplines. In this case, she is implicitly treating the prompt of reasoning skills used to understand physics as being physics knowledge that can be applied elsewhere.

This interpretation of “reasoning skills used to understand physics” in terms of physics content knowledge was shared by Florence, who mentioned this type of knowledge primarily in her explanation of why she doesn’t think about physics in her everyday life.

Interviewer: “Reasoning skills used to understand physics can be helpful to me in my everyday life.”
What type of reasoning skills do you think of when you hear that statement?

Student: Well physics reasoning, why things work the way they do. Why, how come a ball that's sitting, a ball falls and it doesn't keep on bouncing so that kind of thing.

Her emphasis on thinking about the dynamics of a bouncing ball show that she is framing the question about reasoning skills in terms of the utility of physics content knowledge in everyday life.

4.5.1.3 Reasoning Skills as Common Sense

The above responses dealt with skills and knowledge that were expected by the instructors of this course. However several students interpreted this phrase in an unexpected way. The next two students' answers indicate that they felt that “reasoning skills” were more closely connected to everyday reasoning or common sense than to physics.

First Student:

Interviewer: What kind of reasoning skills do you think of when you hear this question?

Nadine: My mind is at a complete blank right now because it seems like we didn't get any reasoning skills from the course. […]

Interviewer: So what would be a reasoning skill?

[...]

Nadine: Reasoning skills that would be involved in your everyday life I guess. Physics 100 just didn't seem like it really affected my life and my choices.

Second Student:

Interviewer: What do you think of when you think of reasoning skills? What did you think of right away?

Patricia: I don't know, somebody not stupid. [...] Yeah there's a certain amount
of reasoning like cars can’t go like a gajillion miles per hour. <Sarcasm> Oh, let’s THINK about that. </Sarcasm> I dunno, yeah there’s reasoning skills. You should be logical but you should be logical in *everything*.

Interviewer: It seems like you’re saying that you walk into the course and you have a certain perspective on reasoning skills. And so my question is. Do you think that you learned those skills?

Patricia: Yeah probably. But I think I learned them through trial and error in real life and certain people’s personalities have more reasoning skills and people are inherently like, “Be logical, you can’t be a dreamer”. Whatever. So that’s applicable to life. If you see things in a way that’s like “This can happen I see this happening, this is reasonable,” I’m sure you’ll be reasonable in most aspects including education and physics.

For these students, it seems that the phrase “reasoning skills used to understand physics” was not distinct from their general perception of reasoning skills used in everyday life. This interpretation would make the CLASS item 30 “reasoning skills used to understand physics can be helpful to me in my everyday life” almost tautologically true. For these students, a positive response on that item says more about their perception of the term “reasoning skills” than it does about the connection between physics and everyday life.

4.5.1.4 Reasoning Skills as Exam-Taking Strategies

One student interpreted reasoning skills as primarily exam-taking skills.

Samantha: The organizational skills that I learned in physics can be helpful to me. But that has very little to do with the physics.

Interviewer: What other types of reasoning skills do you think, come to mind.

Samantha: There’s a lot of process of elimination. Because I didn’t necessarily understand it but I was like: it can’t be that, that doesn’t make sense here. There’s a lot of process of elimination which is a good skill to be able to do. There’s a lot of just like, thinking back to trying to write the exam, trying to the interpretation of questions. Trying to understand what he’s actually asking.

For Samantha, “reasoning skills used to understand physics” were primarily utilitarian skills such as interpreting exam questions and applying the process of
elimination. This suggests that for her understanding physics is the same as doing well on the physics exam.

This interpretation is supported by earlier statements that Samantha had made about her approach to the course’s open-book exam. She described how her exam preparation consisted almost exclusively of indexing and organizing her notes so she could look things up quickly during the exam. For her, “understanding physics” was very closely connected to “understanding how to pass the physics exam.”

4.5.2 Conceptions of Physics in the Real World

Students’ responses in these interviews illustrated a wide diversity of ways in which students perceived connections between classroom physics and the real world. This was especially important because the course instructors had been thinking of “real-world connections” in an implicitly unitary fashion and had assumed that by addressing important questions presented in familiar contexts the students would see the importance of physics in their everyday lives. These interviews made it clear that these assumptions needed to be critically re-examined.

There emerged from the interview transcripts several different varieties of the notion of a connection between physics and the real world. Interviewees evidenced that they could believe strongly in one form of real-world connection while rejecting another. In the following sections some of the different ways that students described connections between physics and the real world are described and illustrated with excerpts from the interviews.

4.5.2.1 Physics as Relevant Environmental Issues

When prompted by the CLASS statements many students expressed their belief that physics is connected to the real world. However, they did so in a way that connects it to large environmental issues rather than everyday life. Because climate change was a key aspect of the course curriculum, it is not surprising that students would mention the connection between physics and this issue.
The quote below illustrates how a student may think of real-world connections in physics at the level of a large issue.

*Beryl*: *[Learning about physics] opens my eyes to global warming and the other crisis in the world. So I’m more aware of them if I learn more about them and like if you don’t know about then, if you don’t really know that something like this exists.*

The next quote illustrates how one student distinguishes between the relevance of the overall topic as opposed to the relevance of the component elements of the physical theory of that topic that was presented in class.

*Debby*: *I think it connects, just not to a point where you would actually think of it in day to day life. Like global warming, pretty big issue, it matters. But then when we’re talking about the solar flux or something, I don’t remember, it just didn’t seem relevant.*

This type of split illustrates the fine nuances of students’ perceptions of “real-world connections”; their perception of the relevance of physics to the real world may be very fine-grained, and susceptible to highly personal preferences.

This distinction in students’ and experts’ epistemologies of physics could be explained in terms of the integration of their knowledge. An expert who sees an overall theory as relevant and who knows that the component elements are necessary for understanding and utilizing that theory is likely to see the component elements as relevant as well. The integrated, hierarchical knowledge structure of the expert allows them to attribute the same meaning and relevance to the pieces as to the whole. However, for a student who perceives physics more as “disconnected facts”, the relevance of the larger theory may not imply relevance of the component elements.
4.5.2.2 Physics as Relevant vs. Physics as Worth Noticing

When explicitly prompted to discuss the relevance of “the subject of physics” to everyday life, most of the interviewed students reported that they believe it is deeply relevant to the action of the real world. There is a sense, perhaps merely derived from a perception of science as an authority on the nature of the world that physics is somehow at the root of many everyday phenomena. We can see this in the first part of the quote below.

Florence: The subject of physics itself I’m sure is absolutely relative to my life. I’m sure that all the things that I do in life have some physics component behind them...

However, the second part of that same quote reveals another conception of how physics might connect to the real world.

Florence: …but at the same I don’t think about it like that. I feel like it doesn’t but in my head I know that somehow it does. I’m obviously walking, there’s a force of gravity on me so that’s physicsy but like but that’s not what I think about when I walk across the room.

I just go through my days, and I don’t really give it a thought. Or like when I turn on a lamp, I don’t think how electricity is traveling.

Another student’s quote demonstrates this same split between belief in the relevance of physics and the perception of that relevance.

Vivian: I know [physics] is relevant and everything, [the instructors] make everything applicable to the real world which is important. I am not passionate about it so I don’t really make it relevant. I could make it relevant if I was really interested in it.

4.5.2.3 Physics as Calculations

In response to being asked to agree or disagree with one of the CLASS prompts, another interviewee reported that she believes physics has little relation to the real world based on her conception of the nature of physics as mostly calculations.
Interviewer: (prompting student to agree or disagree with the following statement) “The subject of physics has little relation to what I experience in the real world.”

Helene: I would say I agree with that. Because I don’t know, what I think of physics is mainly like calculations and things like that. And it doesn’t seem like I ever do them in real life.

Rather than saying she simply doesn’t think about it, she is expressing her belief that the main activities in real life are distinct from the main activities in physics. For her, it seems to make little sense to connect physics and real life.

**4.5.3 Factors Influencing Perception of Relevance**

Two main factors that influence students’ perception of the relevance of physics to the real world emerged from these interviews. The first is that students in this population tended to judge relevance based on their immediate lives or stated career goal. The second factor is that students reported that problems with a fantastic or humorous setting sent a message that physics was only applicable in such settings. These factors are discussed in the sections below.

**4.5.3.1 Personal Perspective on Real-World Relevance**

These interviews also revealed some general differences in the students’ and instructors’ perceptions of what constituted a real-world connection in physics. As mentioned above, students’ comments indicated that they made a clear distinction between relevance to the world at large and relevance to themselves personally. This result was not surprising as it echoes the split found by Adams et. al in their development of the CLASS survey [54]. However an important pattern that emerged was that students generally assess relevance to themselves based on direct past experiences, current interests, and current career goals. They reported little interest or feeling of relevance for physics set in real-world contexts that do not fall into these categories. Several students commented that they did not see strong connections in problems or contexts that were not relevant to them at the current time.
A good example of this is the case of driving. Several students complained that using driving as a context for mechanics problems isn’t directly relevant to students that don’t have a drivers’ license or a car. The student below describes how she doesn’t think about acceleration or velocity because she doesn’t drive.

Wendy: We don’t really think about [kinematics] I guess. I don’t drive yet. So then can’t really apply the kinematics of like acceleration or velocity or anything. You don’t really think about it when you’re just walking or taking buses or something like that.

This result was in conflict with the instructors’ expectations, and started to reveal the difference between the students’ and instructors’ perception of real-world relevance. This underscored the importance of understanding and addressing the students’ beliefs rather than the instructors’ beliefs about these contexts. Subsequent polling of the students revealed that the majority of Physics 100 students didn’t drive a car on a regular basis, which prompted a shift within the second year of the course towards more kinematics questions related to busing, cycling, and walking.

These results also prompted an increased focus on contextualizing the course physics in terms of the students’ everyday life at the present time, rather than their hypothetical future.

4.5.3.2 Interpretation of Realism of Tutorials

Another result that is important to anyone writing physics word problems was that students found some of our recitation problem situations unrealistic or fantastic. Two problems in particular were cited in the interviews: the first involved calculation of thermal energy balance for an unfortunate astronaut who had only a black garbage bag for a space suit, and the second involved calculation of friction for a stuntman stuck on the front of an accelerating train. For the complete text of the recitation problems see appendix A.

One interviewee explained that she felt that problems such as these send the message that physics is only relevant in unrealistic or comical situations such as these.
Valerie: I remember one question on whether heat would be absorbed or reflected, the astronauts used garbage bags instead of their suits. But that would be unrealistic. [...] I think these kinds of questions, they seem so unrealistic, it makes us think that physics doesn't relate to us. And it can't relate to us, because the recitation problems are connecting us to unrealistic situation. They are kind of saying it can't connect to everyday situation. But instead they have to make it into an unrealistic situation. Kind of comical, astronauts in garbage bags, a comical situation instead.

Considering the widespread use of fantastical or humorous situations as contexts for physics problems, this comment has important instructional implications, which are discussed in the Chapter 7 of this dissertation.

4.5.4 Summary

In this chapter I used interviews to examine students’ responses to the CLASS survey questions that contribute to the Real-World Connections and Problem-Solving categories. I demonstrated several different ways that students interpret the phrase “reasoning skills used to understand physics” which is used in question 30 of the CLASS survey.

I also identified several different interpretations of the ways in which physics is relevant to the real world. In general, students tend to distinguish between relevance to others and relevance to themselves and judge relevance to themselves based on their immediate current circumstances and career plans. This shows the importance of learning about students’ everyday lives and career plans in order to demonstrate relevance to them.
5 STRUCTURED REAL-WORLD RELEVANCE INTERVIEWS

The unstructured post-course interviews had shown the variety of ways that students might perceive relevance to the real world, as well as giving us a look at the kinds of problem features that novices react to in developing those opinions. While students’ professed opinions and their actions with respect to a particular problem in the real world may not be the same [11,56,57], their stated opinions still offer valuable insight into their beliefs.

Because of the unstructured nature of the study described in chapter 4 it was rare for more than one student to comment on the same physics problem or problem feature. In order to learn more about which problem features promote the perception of relevance for a wide variety of students, a more systematic study was required. In this study, a diverse cohort of students were interviewed on their opinions on a set of scientific problems that were designed to span many different features that could prompt a judgment of relevant or irrelevant to the real world.

Students were asked several questions about each problem and I performed a qualitative analysis of their responses to identify the features that each student cited as motivating their perception of relevance. To explore which problem properties were statistically correlated with higher overall ratings of a problem’s connection to the real world, I coded the interview results and performed an ANOVA analysis.

Below, I describe the goal, methodology, and results of this study.

5.1 Goal and Research Questions

As stated above, the purpose of these interviews was to systematically examine students’ opinions of the real-world relevance of a fixed set of problems. The features that students cited in their justification for their judgments help to answer the following research question:

What features of scientific problems do students see as connected to the real world?
5.2 Methodology

5.2.1 Interview Cohort

These interviews were conducted in the spring of 2009. To ensure a diverse cohort the interview participants were recruited from the general student population via poster advertisements that encouraged students who “Love Science” or “Hate Science” to apply. Posters were placed in the student union building, the main university bookstore, and in the university libraries. In addition, participants were recruited via in-class recruitment from introductory physics and astronomy classes that served non-major populations. The final cohort of participants was ten undergraduate students who spanned a wide variety of declared majors and experience in university. See Table 11 for a summary of these students’ backgrounds.

As a part of the interview protocol (see below), the participants were asked to respond to the four questions in the CLASS survey’s real-world connections category. The last column of the table gives the students’ scores in this category. A higher number means the student reports more expert-like beliefs about the relationship between physics and the real world. Although I attempted to recruit a cohort that was equally distributed in terms of their stated beliefs about the real-world relevance of physics, only two of the students scored less than 50% on the CLASS questions administered in the interview.
<table>
<thead>
<tr>
<th>Gender</th>
<th>Yr.</th>
<th>Major</th>
<th>% Favorable on CLASS Real-World Connections scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>3</td>
<td>Clinical Psychology</td>
<td>100%</td>
</tr>
<tr>
<td>F</td>
<td>4</td>
<td>Accounting</td>
<td>100%</td>
</tr>
<tr>
<td>F</td>
<td>3</td>
<td>Chemistry / Global Resource Systems</td>
<td>100%</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>Science, transferring into Commerce</td>
<td>25%</td>
</tr>
<tr>
<td>M</td>
<td>3</td>
<td>Psychology</td>
<td>75%</td>
</tr>
<tr>
<td>F</td>
<td>4</td>
<td>Kinesiology</td>
<td>100%</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>Science</td>
<td>100%</td>
</tr>
<tr>
<td>M</td>
<td>5</td>
<td>Philosophy</td>
<td>50%</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>Arts One</td>
<td>100%</td>
</tr>
<tr>
<td>F</td>
<td>3</td>
<td>Human Kinetics</td>
<td>75%</td>
</tr>
</tbody>
</table>

Table 11: Summary of structured real-world connection participant demographics. The last column of the table gives the students’ score on the CLASS survey Real-World Connections category. A higher number means the student reports more expert-like beliefs about the relationship between physics and the real world.

5.2.2 Interview Protocol

The CLASS survey explicitly probes students’ attitudes towards real-world connections in physics. However it does not explain why students answer the way they do. For this study we used the questions from the CLASS “real-world connections” category as a base, but then investigated students’ perspectives more deeply via interview.

The students were individually interviewed following a semi-structured protocol. Following the recommendation of diSessa [55] the interviews were conducted in a spirit of mutual inquiry; participants were asked to share their privileged knowledge of how typical students perceive scientific questions. The goal of the study was explained as “exploring how you see the connection between science and the real world”. The interview began with questions about the students’ background and personal history, and then proceeded to giving the four CLASS questions from the Real-World Connections cluster verbally and asking students to answer and explain their response. These questions are listed previously in Table 7.
A particular student’s perception of a particular problem is the result of an interaction between the properties of the problem and that student’s particular experience, personality, and framing of the problem. The purpose of these interviews was to identify the criteria that students use when making judgments about the connection of problems to the real world and to explore the relative importance of these criteria. In order to support this exploratory aim, the study was structured to solicit the perceptions of a wide variety of students on a wide variety of scientific problems.

Students were then presented with a series of problems drawn from real science courses and two abbreviated news stories about scientific issues. The participants were instructed to read these problems but not to solve them. These spanned a variety of problem types (short answer, multiple choice, and news story) and science disciplines (mathematics, physics, biology, chemistry, astronomy). They are listed in full in Appendix C.

After the participants had read and considered a particular problem the interviewer asked four questions to probe different ways they might see connections between these problems and the real world. These questions were developed from a pilot study with two students and are intended to span the different ways in which student in the pilot study expressed different types of real-world connections to scientific information. These questions, referred to hereafter as Reality Link Questions or RLQs, are listed below.

1. Do you see this problem as connected to the real world? Why or why not?

2. Do you think that learning more about the topic of this would be useful in your life? Why or why not?

3. Would thinking about any of your own experiences help you to interpret this question /statement? Can you give an example?

4. What kind of person might find (the solution to a question like this / this statement) useful?
The participants were prompted with these four questions and encouraged to explain their reasoning wherever appropriate. After a student indicated they were done with a particular question I moved on to ask the next. Then the student proceeded on to the next science problem, and each of the four Reality Link Questions were asked in order to probe the student’s reaction to that problem. The interviews were audio-recorded for analysis, and I took field notes during each interview.

5.3 Qualitative Analysis and Results

The audiotapes of the interviews were analyzed by both qualitative and quantitative means to investigate which features of the problems the participants saw as connected to the real world.

To perform the qualitative analysis I reviewed the audio-recorded interviews to identify overall patterns in students’ responses as well as specific “triggers”: features of the problems that students explicitly cite when justifying their judgments of whether a problem is (or isn’t) connected to the real world. In addition, any feature that was described as generalizable to other circumstances was counted as a trigger. Triggers were interpreted based on the single main reason the student gave for or against the connection between a particular problem and the real world.

The use of the word “trigger” is rooted in the Framing and Resources perspective of how students make these real-world connections. When they read a particular problem, certain aspects of the problem may remind them of (or activate) other knowledge that allows them to interpret and contextualize the problem. For this study I identify problem features that trigger their access to their real-world knowledge, which they employ to judge the relevance of the problem to the real world.

I identified five main categories of triggers: Formalisms in the Problem, Connection to Problem Context, Personal Consequences of Problem, Broad Consequences of Problem, and Implications for Action. These triggers and overall trends in students’ responses are discussed in the following sections.
5.3.1 Judgment Based on Explicit Context

The largest trend, which echoed one of the results of the interviews conducted with Physics 100 students after the first year of the course, is that students most often evaluate the relevance of a given problem to the real world based on their personal relationship to the explicit context and question presented. For example, a question about how Antarctic penguins’ caloric needs are impacted by the insulative properties of their feathers would be most commonly evaluated based on the participants’ own experience with or interest in penguins or the Antarctic, the explicit subject and context of the problem. However, an expert scientist might evaluate the real-world relevance of that question based on other questions and contexts where the scientific principles in the problem might conceivably apply. For example, an expert scientist might see that the caloric needs of penguins are important in considering the relationship between a penguin population and their prey, or that the principles of thermal conductivity are applicable to understanding the body warmth of a wide variety of animals, protective cold-weather clothing for humans, or even designing home insulation. This tendency of students to evaluate real-world relevance based on their personal experience with the explicitly stated context mirrors Chi, Feltovich, and Glaser’s result that students tend to categorize physics problems based on their surface features rather than on deep structure [26].

5.3.2 Diverse Definitions of Real-World Connections

The questions to probe the students’ perceptions of real-world connections from the science problems were specifically crafted to prompt different aspects of these connections. In students’ responses, several themes in the nature of “real-world connections” emerged.

Firstly, the interview participants (and sometimes the interviewer) rephrased the term “real-world connections” to mean “real world relevance.” Based on the student responses, I believe that the term “relevant” is actually more specific than the more general “connected”; something that is relevant to the real world is certainly connected to the real world, but something that is connected to the real world is not necessarily relevant. I believe the difference is in whether the problem has meaningful
consequences: if a particular problem or issue has consequences but they are not significant or meaningful to the reader, then that problem will not be rated as relevant.

As in the more unstructured interviews conducted specifically with Physics 100 students, this diverse group of students continue to distinguish between relevant to other people and relevant to themselves. I speculate that the latter is more important for motivating learning and meaningful engagement.

5.3.3 Real-World Triggers

After coding the transcripts from all ten students the triggers were grouped into five broad categories. Table 12 below shows the coded triggers and categories. The number in parentheses after each trigger is the number of times it was coded over the whole data corpus.
Table 12: Summary of triggers for real-world connections. The main trigger categories are listed to the left and the subcategories are listed underneath these. The number in parentheses after each trigger is the number of times it was coded over the whole data corpus. Triggers that were generally cited as enabling real-world connections are written in bold font, those that were cited as inhibiting real-world connections are written in italics, and those that could be cited as either enabling or inhibiting real-world connections are written in standard font.

5.3.3.1 Examples of Trigger Coding

To illustrate the trigger coding scheme two examples are presented below of how transcripts were coded for a trigger. In the first example, I have been interviewing the student about a problem in which a landscaper needs to do some calculations in order to determine whether it will be cheaper for him to purchase a smaller truck with better gas mileage or a larger truck with a bigger cargo capacity. The problem is set in the city of Vancouver, and provides all of
the specifications of each truck necessary for making a calculation. The student has already indicated that she thinks that this question is not related to herself, but perhaps to “people who drive trucks”.

Interviewer: Do you think that learning more about this topic would be useful to you in your life?
Valerie: No, I don’t think so.

Interviewer: Why not?
Valerie: Cuz um.. Actually, it might. Because instead of trucks it could be, like a car and you could be driving people.

Interviewer: OK, so how does that change… How would that… would that be relevant to your life?
Valerie: No, cuz in real life I don’t think we would really be calculating stuff to see which one is a better deal or a cheaper investment.

Interviewer: Mm hm. So, it’s the calculation?
Valerie: Most people don’t really sit down and do the math to see which one is cheaper. They probably just go and, like “right there, Ill take that one” Maybe a rough estimation. Not, like, actual math.

Interviewer: So what’s the difference between a rough estimation and actual math?
Valerie: I dunno (laughs). Actual math is when you sit down and write all the numbers, do the actual calculating. Estimation is when you just do it in your head and round everything off.

In this exchange we see the student begin to generalize from trucks to other types of vehicles, which makes her reconsider her earlier claim that the problem is only relevant to “people who drive trucks”. However, even in light of this new perspective she remains firm in her opinion that the question is not relevant to the real world, citing her belief that people don’t engage in detailed calculations. This passage was coded as a “Calculation” trigger.

In another transcript, presented below, a different student gives his opinion of the same problem.
Interviewer: Do you feel like this question is connected to real life?

Chris: A hell of a lot more [than the previous question] Yeah, absolutely

Interviewer: Why is that?

Chris: Almost everybody drives. Personally I don’t, but almost everybody drives. Almost every business needs to consider fuel costs as a part of their operating overhead. Even if it’s not necessarily transporting a large amount of goods. Even if it’s just cars moving small objects from A to B they need to understand the fuel costs, and how much they’re going to spend.

And not purely from a financial perspective. I mean we could use this and the money and turn it into terms of how much gas is necessary to be consumed per day by the area of Vancouver based on the figures given by a certain number of companies that do this sort of thing. And you’ve got a projection there for how quickly we consume fuel versus how the city needs as a whole. This is useful to everyone. Urban planners, business owners. You live at home, you just need to figure out, well I only drive to and from work. This allows you to figure out in the long term what the better purchase or lease is for your own personal needs.

In this passage the main reasons this student gives for his perception of the real-world relevance of this problem are that it impacts financial calculations and that driving is a ubiquitous activity. This passage was coded with both the “Money” and “Common Activity” triggers.

5.3.3.2 Categories of Real-World Triggers

Five main categories of triggers emerged from this analysis.

Broad Consequences.

Many of the problems in this study were deliberately designed to be thematically related to environmental or other broad societal concerns. Environmental consequences emerged as a major category of trigger cited by the interviewees. In the following example, an interviewee gives his perspective on the real-world connections in a problem about a bird species’ growth under “ideal conditions” on an island with no predators and unlimited access to food.
Interviewer: What do you think about this question? Is it connected to the real world?

Bonnie: Um, it kind of is, I guess. Because, it kind of explains why things are the way they are right now with evolution and that sort of thing, and it also has a little bit to do with the environment and... destroying animals’ habitats and introducing new animals in places and stuff like that.

Interviewer: So, this has to do with destroying animals’ habitats? How so?

Bonnie: I don’t think it has to do with destroying animals habitats, not this question. But it could be applied to that because this is about if you put them on this island and they have all the food in the world and no predators, and that’s kind of the opposite of a lot of the situations we are facing where we’ve introduced unnatural predators that an animal wouldn’t be facing anyway, and we have issues where pollution is killing sources of food, and that’s a pretty big issue right now. So I think this is related to that and could help you better understand that so you kind of know what people are talking about when they’re talking about environmental crises and stuff like that.

When the student considers this question, it is the connection to environmental consequences that he believes are “a pretty big issue right now” that form the main real-world connection that he perceives. Because this characteristic is cited so clearly, this passage is coded as an Environment trigger.

**PERSONAL CONSEQUENCES.**

Several of the triggers for real-world connections involved personal consequences of the problem being discussed. While these consequences may not have been present in the problems themselves, some students generalized the substance of the problem to mention the potential for impact on themselves. In some cases, triggers in this category were cited as a reason that a problem did NOT have real-world connection. In the following example, a student distinguishes between consequences for others and himself and asserts that despite obvious consequences for the environment, he doesn’t feel that a problem about destruction of ozone by CFCs has personal consequences for his life.
[Student has just read the problem, which concerns destruction of ozone by CFCs and UV radiation]

Ernesto: Well, I guess I could possibly see this being relevant to the real world but... I guess with the environment. I wouldn’t really see applying this to real life for me, but I understand that the environment is important and ... I mean it’s important that the ozone isn’t affected by CFCs, but I just don’t see this applies to everyday life. I mean, if the ozone was gone I guess it would apply to everyday life but... I dunno, I just don’t see it being directly influence to me right now.

Interviewer: It sounds like there’s some conflict there

Ernesto: Well of course there’s this huge thing about the ozone, but I mean... It’s something that I don’t see ever happening where the ozone will completely disappear, and although it’s important for people to take care of the environment I don’t see how this relates to what’s immediately going on in my life, like immediate concerns rather than overall global concerns.

This example was coded as both an Environment Trigger and a Personal Consequences Trigger. Ernesto makes an argument for a real-world connection based on its connection to the environment, but against relevance to himself based on lack of personal consequences.

CONSEQUENCES FOR ACTION.

This category is closely related to personal consequences, but it specifically concerns the implications or possibility for personal actions on the problem topic. In some cases, students say that because the ideas in or results of a problem under consideration would not have any consequences for action, the problem is not connected to the real world. A related trigger is when students say that the problem touches on issues that affect them but are beyond their control. In each case, the lack of implications for students’ choices is cited as a reason for a weak real-world connection. These triggers are typically cited as reasons that a problem does not have a real-world connection. Two examples of this trigger are listed below.
In the first example, Danielle explicitly says she doesn’t think understanding a particular problem would be useful because it wouldn’t change her behavior. This is a clear example of lack of personal consequences.

*Interviewer:* Do you think that learning more about [the problem involving insulation of antarctic penguins] could be useful for you in your life?

*Danielle:* No, I don’t really think so.

*Interviewer:* Why not?

*Danielle:* Because it wouldn’t really change my behavior, whether I knew a lot about this topic or not. I would still think about things in the same way. Like if I was going outside and deciding what to wear, like… stuff like body temperature I wouldn’t really think of it differently after learning this stuff.

In the second example, Fiona says that a question about ozone destruction is not relevant to the real world because she has no personal control over the destruction of the ozone. Therefore this question has no consequences for her actions.

*Interviewer:* Do you feel like this question is connected to the real world?

*Fiona:* Like typical real world, no. But… not really, because we can’t control the UV radiation from the sun. We can’t control that right? (Laughs) I don’t think we can control it cuz it’s from the sun, right? So… I don’t really see how that would help in any way. It might help in understanding concepts but… helping it, like… helping the ozone destruction. I dunno. I did chemistry this summer so, I don’t.. I forgot about it.

*Interviewer:* Well you don’t have to answer this question, that’s not really what I’m asking. What I’m asking is, if you see this question do you think that it’s relevant to the real world?

*Fiona:* Relevant to the real world? To people who study global warming I guess. To me, I won’t really care about this question.

*Interviewer:* Why not?

*Fiona:* Cuz I won’t really know how to save the world, even if I do know the answer to this, right? (laughs)

*Interviewer:* OK, so you won’t care because even if you know the answer to
Fiona: Cuz it’s about ozone destruction right? So even if I do know the answer it’s not like I can do anything about it.

Interviewer: OK

Fiona: Yeah, even if I’m really advanced in this I won’t be able to do anything about it.

Fiona’s statement that “I won’t be able to do anything about it” is the justification she gives for saying “I won’t really care about this question.” Her lack of ability to affect the ozone layer (meaning that there are no consequences for her actions) is the reason she gives for her judgment that this problem is not relevant to her.

**Connection to Context.**

This category of triggers covers situations when students cite specific familiarity with the problem context. In these cases students typically say that the problem has an obvious real-world connection because of its similarity to their personal experience. While some of these triggers are quite specific and rare, such as the student who had previously worked with Antarctic penguins during a summer work-study program, many of them are rooted in common everyday experiences such as driving or riding the bus. These triggers are exactly what we hope for when setting problems in an everyday context.

In the following example a student has just read the problem about the landscaper making a buying decision between two trucks with different mileage and cargo capacity (mentioned above). Without being prompted she volunteers several opinions on the question.

Hermione: I think it’s an extremely important thing to be able to do. This one […] I don’t have to stretch to think of ways that it could be handy. In fact I was looking at buying a car last year, and that had mileage vs. initial cost vs. all those kind of things was definitely a big thing that I was looking at. Although in the end I decided not to buy a car at all.
Interviewer: OK. So would you say that this question is connected to the real world?

Hermione: Definitely.

Because she cites her personal experience in direct connection to the subject of the question, this section is coded as a “Personal Familiarity with Context” Trigger (as well as a “Money” trigger from the Personal Consequences category).

**FORMALISMS.**

This category is a collection of negative triggers in which students say a problem is not connected to the real world because of one or more abstractions or mathematical formalisms present in the problem. Examples include problems that contain formulae, mention extreme simplifying abstractions, or contain calculations in a real-world context where the student believes they are unwarranted. In the example below, a student gives his perspective on the problem concerning population growth of a species of bird under “ideal conditions”

Chris: [immediately after reading the problem] Um, it’s a useful mechanism for explaining Darwinian evolution. And again, you have a systems approach and you can abstract out to any kind of predator-prey scenario, or any kind of human habitation. Once you understand the numbers behind when we go to a certain area, and the resources we consume and what we need.

But its still kind of… ideal conditions, no predators, unlimited food is not a real-world situation. The problem is simplified to the point where it’s no longer... you know it’s not connected to the real world because of those three conditions.

Interviewer: Which three?

Chris: Ideal conditions, no predators, unlimited food

[Later in the discussion of the same problem]

Interviewer: So what kind of people do you think would find the answer to this
question useful?

Chris: Well no-one, because it’s ridiculously idealized. I can appreciate that in low-level science you need to simplify the problems as much as possible so people can kind of understand the core concept and then you can start adding complications. But without those complications the answer isn’t interesting. Because this situation does not exist. It only exists the complications. So in and of itself it’s only useful as a tool to gauge whether or not the student understands the core concept. So I don’t think anyone would find the answer interesting, from that perspective.

While the student does point out the potential value of an idealized question in an educational setting, he clearly believes that the idealizations negate the problem’s connection to the real world. This segment was coded under the “Unrealism of Model” trigger.

5.3.4 Discussion

The perception of the relevance of a particular problem is an interaction of the problem’s characteristics and the student who reads it. Many of the above-mentioned triggers are clearly related to particular elements of a student’s past history and personal experiences which are difficult for an instructor to control. This suggests that it may not be possible to create problems that have real-world relevance for most students.

5.4 Quantitative Analysis and Results

The importance of students’ idiosyncratic histories and expectations in perception of real-world relevance suggests that perhaps attending to particular problem features as an avenue for promoting the perception of relevance is missing the point. Indeed, the qualitative analysis makes it clear that these factors are extremely important. However, it is also clear that some problem factors are important to many students, and it is certainly possible to develop problems that are “better” than others, in the sense that they are more likely to offer students an opportunity to connect their own particular history to the problem context. For example, problems set entirely on Mars would offer students very
little opportunity to do so, whereas problems set in their hometown would be comparatively more likely for students to connect with.

In the interest of examining whether there are problem characteristics that broadly increase students’ perception of the connection of a problem to the real world, coding was performed on the problems and student responses and an ANOVA analysis was performed to identify which problem features were significantly correlated to higher overall ratings of relevance.

5.4.1 Coding of Problems

The problems were coded for several main characteristics that showed up in the trigger analysis and could be coded objectively. The problem characteristics that were coded are listed on Table 13. The complete list of problems can be found in Appendix C.

Because of the Calculation and Formulae triggers, the problems were coded as to whether they required a quantitative answer and whether they contained obvious formulae. To correspond with the Money trigger the problems were coded as to whether they explicitly involved a financial aspect. Finally, to correspond with the Connection to Context trigger the problems were coded based on whether they were set in an everyday context: a code of 0 was given to problems with no attempt at a real-world context; 1 was given to problems with a real-world context that was unlikely to have been part of a typical university student’s experience, and 2 was given to problems set in an everyday context. These codes were independently conducted by two independent researchers with 90% agreement before discussion and 100% agreement after discussion. Note that in subsequent analysis, these codes were treated as ordinal (rather than a scalar) values.
Table 13: Properties of scientific problems used to probe students’ perception of relevance to the real world. Columns 2-5 were coded by the researcher. The Environmental rating is based on the number of environmental triggers mentioned by the participants in study.

Because of the large number of instances of the Environmental trigger I attempted to code the problems based on degree of connection to environmental issues. However it was difficult to judge the “direct-ness” of environmental connections, and the inter-rater reliability of these codes was only 60%. Rather than try to code the problems as environmental or not a priori, the interviewees’ own triggers were used to assign an Environmental rating to each problem. The rating for each problem was the number of triggers (out of ten students) that were coded for that problem.

### 5.4.2 Coding of Responses to Interview Problems

In order to quantify students’ perception of the real-world relevance of each of the test problems, students’ responses to the four Reality Link Questions were coded to assign a value to each response. The Reality Link Questions are listed in section 5.2.2 above. Note that students were not asked to explicitly give a numerical answer during the recitations. I assigned these codes afterwards by reviewing the taped interviews.
The first three questions are yes/no questions, and responses were coded on a three point scale for yes, no, and neutral / mixed. The fourth question asks “What kind of person would care about the answer to this problem?” Students’ responses were coded according to the degree to which they generalized from the particular context in their answer. For example, several students responded that the answer to the question about penguins in Antarctica would only be of interest to a penguin researcher. These responses were coded as a 2. One student generalized on the context of “a cold place” and replied that the answer to this problem would be of interest to anybody that lived in a cold climate. This response was coded as a 3. This coding scheme is summarized in Table 14 below.

<table>
<thead>
<tr>
<th>Code</th>
<th>Response to RWC Q 1-3</th>
<th>Response to RWC Q 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>Nobody</td>
</tr>
<tr>
<td>2</td>
<td>Neutral/Mixed</td>
<td>Specialist in context; slight generalization from context</td>
</tr>
<tr>
<td>3</td>
<td>Yes</td>
<td>Broad generalization from context</td>
</tr>
</tbody>
</table>

Table 14: Coding scheme for responses to Reality Link Questions. In each case, a code of 1 indicates the student reported that they perceived little or no real-world connection in that category, a response of 3 indicates a strong real-world connection, and a response of 2 is neutral or mixed.

In this manner, a code of 1, 2, or 3 was assigned to each of the students’ answers to the four Reality Link Questions corresponding to each of the test problems. In subsequent analyses, these codes were treated as ordinal rather than scalar data.

### 5.4.3 Statistical Analysis of Codes

Statistical analysis was conducted using the R software package [58] to examine which problem characteristics were correlated with significantly higher results on the above-mentioned interview scores. The codes for responses to the Reality Link Questions were treated as ordinal (rather than scalar) data, meaning that while a 3 is definitely better than a 2, it can’t be argued that it is precisely 50% better than a 2. Taking means of these data is not meaningful so nonparametric statistical tests were used. While the responses to the four real-world connection questions are clearly related, the analyses were performed for each question individually to avoid the
assumption that a “3” on question 1 is somehow the same as a “3” on question 4. Because the data on these ordinal scales cannot be considered normal, nonparametric statistical tests were used. Due to lack of time during the interviews problems 9 and 10 were only completed by a single student and were therefore eliminated from the analysis.

Based on the student interviews it was assumed that the Money trigger would increase the results, so this was examined with a 1-tailed Mann-Whitney test to see if it made a significant difference to the results. Similarly, it was assumed that the presence of formulae in a problem would decrease the real-world connection ratings so this was also examined with a 1-tailed Mann-Whitney test. Due to some mixed comments on the connection between calculation and everyday life, the Quantitative factor was examined with a 2-tailed Mann-Whitney test.

The Environmental code and the Everyday Context code were both examined with two tests: a 1-tailed Spearman Rho test examined the probability of a nonzero correlation between the ordinal code and the results. However due to the low number of problems a second test was conducted to increase the power of this test: the Everyday Context analysis was used to split the problems into two groups: Weak Everyday Context (coded 0 or 1, N=5 problems) and Strong Everyday Context (coded 2, N=2 problems) and a Mann-Whitney test was conducted to see if there were any significant differences between the results of these two groups. Similarly the Environmental code was used to split the problems up into two groups: weak Environmental (coded 0-4, N=5 problems) and strong Environmental (coded 5 or higher, N=3 problems).

The results of these initial tests are summarized on table 15 below.
Table 15: P-values of tests to examine the relationship between problem characteristics on student responses to Reality Link Questions. *(p < 0.1), **(p< 0.05), ***(p < 0.01).

According to these tests the problem characteristics with the most significant correlation with the real-world question results was the Money characteristic, which showed a significant difference in all four real-world connection questions (p<0.05) . The Everyday Context rating also showed a strong relationship with the results. The spearman rho test showed a significant correlation for Reality Link Question 2 (rho=0.23, p<0.05) and Reality Link Question 4 (rho=0.37, p<0.05). The follow-up Mann-Whitney test on the results of high vs. low Everyday Context showed a significant difference with p < 0.05 in three of four questions, and a difference with p<0.1 in the fourth question. The Environmental rating and the Quantitative characteristic also showed a significant difference (p<0.1) in one of the four questions.

Because of the strong results for Everyday Context and Money, an analysis of the interactions between these two characteristics was conducted. The problems were separated into three groups: Group 1 was Strong Everyday Context and Money; Group 2 was Strong Everyday Context and No Money; Group 3 was Weak Everyday Context and No Money. (There were no problems in the study with Weak Everyday Context and Money, so the fourth possibility was not tested). A Kruskal-Wallis test of the relationship between Group number and Reality Link Question results showed that at least one of the three groups had significantly different results for RWC questions 1, 3, and 4 (p<0.05). Subsequent pairwise Mann-Whitney comparison by
group was used as a post hoc analysis to see which groups had better results. These results are summarized in Table 16 and 17 below.

<table>
<thead>
<tr>
<th>Everyday Context &amp; Money Interaction</th>
<th>RWC Q1</th>
<th>RWC Q2</th>
<th>RWC Q3</th>
<th>RWC Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.038**</td>
<td>0.035**</td>
<td>0.103</td>
<td>0.006***</td>
</tr>
</tbody>
</table>

Table 16: P-values of Kruskal-Wallis test to examine the impact of the interaction between Everyday Context and Money on real-world-connection questions. *(p < 0.1), **(p < 0.05), *** (p < 0.01).

<table>
<thead>
<tr>
<th>Test P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RWC Q1</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Group 1 &gt; Group 2</td>
</tr>
<tr>
<td>Group 1 &gt; Group 3</td>
</tr>
<tr>
<td>Group 2 &gt; Group 3</td>
</tr>
</tbody>
</table>

Table 17: P-values of pairwise Mann-Whitney comparisons of average results between the three groups of problems. Group 1 is Strong Everyday Context and Money; Group 2 is Strong Everyday Context and No Money; Group 3 is Weak Everyday Context and No Money. *(p < 0.1), **(p < 0.05), *** (p < 0.01).

These results show that Group 1 (Strong Everyday Context and Money) had higher results in RWC questions 1 and 2 than both other groups, and had higher results than Group 3 for RWC questions 3 and 4 (p<0.05). This indicates that problems that have both an everyday context and have financial implications are significantly more likely than problems with only one of these to be rated as connected to the real world.

5.4.4 Discussion

While Money and Everyday Context were coded as independent problem characteristics, the small number of problems and the small number of participants in this study mean that they may not be measured independently. It is certainly plausible that the problems that involve Money happen to be the ones that are most deeply embedded in Everyday Context. However, the combination of the two factors did emerge as a significant indicator that students would rate the problem highly on the Reality Link Questions.
The fact that only two of the triggers demonstrated a significant correlation with scores on the Reality Link Questions doesn’t mean that the remaining triggers are not important: the small number of questions studied and small number of students limit the statistical power of the tests, so it’s very possible that these other triggers could make a difference if studied with a larger sample size.

The fact that there is some agreement between the qualitative analysis and quantitative analysis of interview data gives us confidence that some characteristics of scientific problems do have an impact on students’ perception of their connection to the real world. While not all the triggers highlighted in the qualitative analysis were found to be statistically significant in the quantitative analysis, the low fidelity of the coding and the low number of students in the study limited the power of these tests. A larger study using Likert scales to probe students perceptions of particular problems would enable a better statistical test of the impact of these various problem characteristics.

5.5 Summary

Qualitative analysis of students’ comments on a wide variety of scientific problems identified five major categories of triggers that students cite as justification for their judgment of a problem’s connection to the real world. The categories of triggers are: Broad Consequences; Personal Consequences; Consequences For Action; Connection to Context; and Formalisms.

Quantitative analysis identified two specific triggers that had a significant effect on students’ overall rating of the relevance of a problem to the real world. When a problem was set in an Everyday Context and contained a Monetary motivation it generated higher ratings of relevance to the real world than problems that had only one or neither of these characteristics.
6 EPISTEMOLOGICAL FRAMING AND REAL-WORLD CONNECTIONS IN STRUCTURED GROUP PROBLEM-SOLVING

6.1 Introduction

Many teachers, researchers, and policy makers have described the importance of connecting science education to real-world phenomena. Recently there has been an increased focus on scientific literacy, which implies that students must not only learn the connections between science education and real life, but must also learn to make use of their science education in order to understand and act in the world [59].

To support the development of their students’ scientific literacy the transformation of Physics 100 in 2007 had an explicit goal of offering students an education in physics that they would be able to apply outside of the classroom. In order to achieve this the course supported development of students’ skill at solving complex real-world problems. As well, we tried to provide opportunities for students to integrate their formal physics knowledge and their real-world knowledge by encouraging them to use their real-world knowledge within the physics classroom.

The Physics 100 recitations were designed to support both of these goals. They are based on research-based methods for promoting development of expert-like problem-solving skills, and are organized around a structured problem-solving strategy that is intended to promote qualitative and conceptual discussion at appropriate times during the solution process. As well, they are set in an everyday context and are designed to enable students to make Real-World Connections by using their own knowledge within the context of the physics course.

This chapter focuses on examining the effectiveness of structured problem solving steps at promoting the use of conceptual and qualitative knowledge during problem solving and on the general characteristics of students’ Real-World Connections in problem solving. In the following sections I will describe my research questions, present my theoretical framework, introduce my coding schemes for analyzing students’ Real-World Connections and epistemological framing, and then discuss the observed relationships between structured problem-solving, framing, and Real-World Connections.
6.1.1 Research Questions

The study presented in this chapter addresses the following research questions.

1. *In what ways do students make use of their real-world knowledge during collaborative group problem-solving?* This question examines the notion of students’ connections between formal physics and the real world within the specific context of their weekly recitation sessions. Students’ use of real-world knowledge is examined via qualitative review of their discourse during group problem-solving to identify categories of ways in which students use their everyday knowledge within the recitation context. These instances of students’ use of everyday knowledge are defined as Real-World Connections, and a robust coding scheme is developed to identify them.

2. *How does students’ framing affect whether and how they make use of their real-world knowledge during collaborative group problem-solving?* This question is the first of two that examine different factors that promote students’ Real-World Connections. It is addressed by coding recordings of students engaged in group problem solving and examining how their Real-World Connections correlate with their epistemological framing.

3. *How does the structured problem-solving strategy affect whether they make use of their real-world knowledge during collaborative group problem-solving?* This question is the second of two that examine different factors that promote students’ Real-World Connections. This question is addressed by coding a variety of recordings of students engaged in group problem solving and examining how their Real-World Connections correlate with the structured problem-solving method used in the recitation.

4. *To what degree are structured problem-solving methods effective at promoting the use of conceptual and qualitative knowledge at the intended times in the solution process?* This question is addressed by coding a variety of recordings of students engaged in group problem solving and examining whether they engage in conceptual discussion when prompted by the structured problem-solving prompts written on their recitation worksheet.
6.1.2 Research Context

The Physics 100 recitations were developed in order to support the two course goals of:

1. enabling students to learn how to apply physics to novel problems outside the classroom and

2. encouraging students to see physics as relevant to themselves and to their lives.

Context-rich problems were chosen for the Physics 100 recitations based on Heller et al.’s result that students working cooperatively to solve context-rich problems exhibited more expert-like problem solving [1]. These problems also offered students an opportunity to practice making simplifying assumptions, an activity that is essential for solving real-world problems but is not developed in conventional educational settings [48].

Initially, we used problems that were directly drawn from the Minnesota online archive of context-rich problems [60]. Based on guidelines developed from my study of students’ perception of real-world connections in science problems (described in chapter 5 above), new problems were subsequently developed that were set in an everyday circumstance, motivated by a plausible reason for calculation, and yielded a result that has clear consequences. The intent was to offer students opportunities to make use of their everyday knowledge within the recitation context and to show them circumstances where physics was relevant to achieving a goal that they found realistic and relevant.

As described in Section 2.4.4 above, the Physics 100 recitations used a structured problem-solving strategy. The same series prompts for each step in the strategy was written on the worksheets each week with an appropriate amount of whitespace underneath.

In order to address the learning curve for dealing with an unfamiliar problem-solving method, the first five recitations were workshops focusing on each of the problem solving steps, similar to the “skills progression” approach advocated by
Teodorescu [20]. This workshop structure echoes Van Heuvelen’s recommendation to “provide students with explicit instruction in the individual skills used by experienced physicists when solving complex problems and then help them combine these skills to solve complex problems” [21]. As much as possible, these workshop problems were also contextualized in an everyday context. After the five introductory workshops the students were required to use the complete problem-solving method to address a single context-rich problem each week.

Students worked in groups of 3 or 4, and each group was given one worksheet to complete. During the year of this study, students were assigned into groups according to the guidelines described in Section 2.4.5.2 above. The students were also required to make use of rotating group roles each week, but informal observations and feedback from the course indicated that these roles were not taken seriously by the students.

6.2 Background and Theoretical Framework

6.2.1 Resources and Framing

One of the key things I study is students’ use of their real-world knowledge within the physics context. During the first few years of the course’s implementation I noticed that even in situations where students had real-world knowledge that was relevant to the physics situation at hand they did not always employ it.

Often, use of knowledge from one domain in another is treated as a purely cognitive task, and is considered from the perspective of transfer. However the notion of transfer does not help us to understand why a student may blithely report an unrealistic and nonsensical answer for a physics problem and then immediately realize that it is nonsensical as soon as she is asked to consider the realism of her answer. It seems implausible that her knowledge of the real world and her capability of making connections between the calculated result and her experience has changed quickly enough to explain this phenomenon.

Instead of considering this phenomenon as an example of transfer I use the theoretical framework of Resources and Framing to help understand why a student
might not make use of her common sense in one moment but then be able to in the next moment. This theoretical framework proposes a structure whereby a particular frame can activate or inhibit certain resources [28,61,62]. As I will explain below, it is the change in a students’ frame that explains why they may be able to access their real-world knowledge one moment and not the next.

Resources are fine-grained elements of knowledge that may be accessed as a part of the process of thinking about something. The kinds of resources that I am most interested in are cognitive (having to do with declarative knowledge or processes) and epistemological (having to do with the nature of knowledge and its construction). Resources are connected to each other and activation of a particular resource can excite or inhibit the activation of another resource. Through networks of mutual activation and reinforcement, resources are commonly activated in networks.

The notion of a frame helps us to describe overall patterns in these activations, and to connect the notion of resources to linguistic analyses [63]. A frame is a person's implicit sense of the essential nature of the activity that they are engaged in. It is their answer, which is often subconscious or implicit, to the question “what's going on here?” The implicit sense of the nature of knowledge and learning that a person is using in their present moment is called their Epistemological Frame. A person’s epistemological frame can govern which knowledge is valued, what is regarded as “the right answer”, and which strategies are employed in order to get it. While a person’s epistemological frame is usually consistent from moment to moment, it can change rapidly in response to new information, interaction with conversational partners, or other prompts.

The theory of Resources and Framing helps us to understand the example given above. If a student initially frames her activity as working on a physics problem, she may take that to entail that only physics knowledge is relevant. This might lead her to unquestioningly trust the results of mathematical calculation. That same framing of working on a physics problem may lead her to hold the implicit belief that her own knowledge about the real world circumstance is not valid or valuable, and so she might never think to compare the mathematical answer to her own knowledge of the
physical situation. She treats the problem as a puzzle or exercise rather than as an investigation into a model of the real world which has a meaningful connection to real events. An instructor’s inquiry or suggestion can trigger her to change to a new frame where she treats her result as representative of a real quantity, upon which point her common sense about the real world may be activated and brought to bear. A change in framing grants the students a new perspective, and allows her to access her everyday knowledge.

6.2.1.1 Review of Scherr and Hammer Coding Scheme

To identify students’ framing during group problem solving I use a coding scheme that is based on one developed by Scherr and Hammer [64]. In this section I review Scherr and Hammer’s coding scheme as presented in their 2008 paper.

Scherr and Hammer’s key claim is that “behavioral clusters” - groups of vocal and bodily gestures that tend to co-occur - are evidence of and mutually interact with student epistemologies. They describe four stable epistemological frames that are evidenced by student behavioral clusters, are shared by all group members, and correspond to patterns in the group’s approach to knowledge and learning.

By conducting detailed analysis of patterns of students’ behavior as well as the thinking that is inferred from their speech, Scherr and Hammer showed connections between the substance of individual students’ thinking and the nature of behavioral interactions among members of the group. They concluded that verbal and nonverbal displays reinforce implicit messages about an individual’s epistemological framing, contributing to the participants’ mutual understanding of what is taking place. These meta-messages carried in behavioral cues help groups to construct their mutual epistemological frame and coordinate shifts between frames.

Their analysis of students’ framing during collaborative problem solving was conducted on videotapes of groups of four students working on specially-
constructed tutorials that explicitly solicit and address students’ everyday knowledge and epistemological resources [65]. Each student completes their own worksheet but they are frequently instructed to discuss ideas with each other. The groups studied were selected based on the fact they were consistently on task and tended to talk to each other frequently.

Based on their analysis, Scherr and Hammer identified four main clusters of behavior which correlated with particular practices with regards to developing and validating the knowledge under consideration. Based on the mutual coherence of these behaviors and epistemological practices, Scherr and Hammer argued that the four behavioral clusters correspond to four distinct epistemological frames. The four frames from their scheme are listed on Table 18 below.

<table>
<thead>
<tr>
<th>Blue: Worksheet Frame</th>
<th>Green: Discussion Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behaviour</td>
<td>Expectation</td>
</tr>
<tr>
<td>Hands quiet, face</td>
<td>Minimal interaction,</td>
</tr>
<tr>
<td>neutral</td>
<td>individual activity</td>
</tr>
<tr>
<td>Body leans forward,</td>
<td>Attention belongs on</td>
</tr>
<tr>
<td>eyes on paper</td>
<td>the worksheet</td>
</tr>
<tr>
<td>Brief glances at</td>
<td>“Check-ins” expected</td>
</tr>
<tr>
<td>peers</td>
<td>Peers not attending to</td>
</tr>
<tr>
<td>Muttering</td>
<td>details of speech</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Red: TA Frame</th>
<th>Yellow: Joking Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behaviour</td>
<td>Expectation</td>
</tr>
<tr>
<td>Sit up straight,</td>
<td>Attention belongs on</td>
</tr>
<tr>
<td>eye contact with</td>
<td>TA</td>
</tr>
<tr>
<td>TA</td>
<td>Rehashing thinking</td>
</tr>
<tr>
<td>Reduced gestures</td>
<td></td>
</tr>
</tbody>
</table>

Table 18: Four behavioral clusters and associated epistemological frames. Scherr and Hammer argue that these behaviors in group problem-solving constitute evidence for students’ current approach towards knowledge and learning.
The four frames described by Scherr and Hammer are:

1. the Worksheet frame, where students’ attention is on the worksheet and their implicit understanding of the task is completing the worksheet task

2. the Discussion frame, where their attention is on each other and their implicit understanding is that they are discussing each others’ ideas

3. the TA frame where their attention is on the TA and they understand their task to be paying attention to the TA

4. the Joking frame where their attention is unsettled and they understand themselves to be joking around.

The bulk of the students’ meaningful engagement with the physics content occurs in the Discussion and the Worksheet frames. In the Discussion frame sitting up, speaking clearly, and gesturing frequently appears with novel reasoning and mutually-constructed understanding. Scherr and Hammer state that in the Discussion frame “the substance of students’ conversation is the physical events under consideration.”

Conversely, in the Worksheet frame students’ attention is on their worksheets and their body language and speech display an expectation that they will not be meaningfully communicating with each other. There is often some speech in this frame however; Scherr and Hammer say that students in the Worksheet frame “do often speak to one another, typically reading from the worksheet, giving brief status reports of their progress, and requesting or providing information”. They state that these interactions are primarily to convey information in support of completing the worksheet.

During the recitation, student groups will transition between these different frames as the focus of their interaction shifts. A group’s frame can shift in response to any external cue or in response to a bid from one of its members. Scherr and Hammer argue that behaviour by one student that does not fit with the current behavioral cluster is often an implicit bid for the group to change to
a new frame. Sometimes bids are ignored, and the rest of the group continues in the current frame. At other times another group member will take up the bid by responding in the new frame, effecting a shift of the whole group’s focus over to a new frame.

Scherr and Hammer note that analysis of framing can be conducted at different scales. If one is focused on the individual cognitive perspective, one can conceptualize frames as being a property of the individual, and communication among individuals in a collaborative group serves to communicate about their own framing and coordinate frame transitions among the group. However, one could also take the perspective that the frame is a property of the group itself, and all of the speech at and body language of the group are evidence of “the group’s frame”.

For my work, I will take more of the former view, although I will assume unless there is evidence of the contrary that a group tends to share the same frame.

6.2.2 Real-World Connections

6.2.2.1 Definition of Real World Connection

Some physicists might object to the notion of “real-world connections” as being somehow distinct from the normal study of physics. For many physicists, the study of physics is the study of the real world. However research has shown us that the belief in the deep correspondence between physics and the real world is a belief most commonly held by experts and students do not always see things in that way. In the development of surveys of students' beliefs about physics, both Redish and Adams have noted the tendency for novices to treat physics as being separate from the real world [13,54].

The resources and framing theoretical framework offers us a way of operationalizing the notion of real-world connection. I assume that the resources that students develop in physics class are heavily associated with performance in physics class. When addressing a problem posed in the
specialized language of physics problems in the context of a physics class, students are more likely to address that problem by making use of the things they learned in that physics class. In the same way, students’ everyday knowledge is developed outside the classroom and is more likely to be activated in those contexts. Within this framework, I define a Real-World Connection as an instance when students cross these boundaries and make use of physics resources in their everyday lives or make use of everyday resources in a physics context.

Note that this definition implies a separation of the world into two spaces: physics class and everywhere else, and I refer to the resources rooted in those two spaces as physics resources and everyday resources. As mentioned above, this distinction is not intended to imply that physics class is somehow not a part of students’ everyday lives, but rather to reflect the separation between the different kinds of knowledge that students commonly perceive.

For the purposes of this study, I will be looking for instances where students make use of their everyday resources in the context of a group physics problem-solving session. The details of my methodology and rationale for our approach will be described in the following sections. However first I will discuss why these real-world connections are important to promote and study and then discuss some of the prior research that attempts to investigate real-world connections.

6.2.2.2 The Importance of Studying RWC in Physics

There are many reasons why science educators and researchers care about making connections between physics and the real world. Principally, making connections between formal physics and everyday knowledge is what makes it possible for novices to learn physics. In order to forge an understanding of new and unfamiliar language, concepts, and representations, a learner must meaningfully integrate these into their existing framework of knowledge and experience [2]. For someone who is not yet an advanced physicist, this means
they must learn physics by interpreting it in terms of their existing conceptions about how things work in everyday life.

There is also evidence that students’ connections between science and their everyday lives are correlated with improved learning and retention. Pugh et al. also found that students who make meaningful real-world connections are more likely to succeed at a delayed assessment and at a transfer task, and suggests that “as students apply the concepts they learn in the classroom to their everyday lives […] they become more fluid and agile in thinking about these conceptions, thus increasing their transfer ability” [7].

Making real-world connections in physics can also have a strong impact on students’ perception of the relevance of physics to themselves, with a concomitant impact on their persistence in the field. Osborne and Dillon [66] have found that a lack of perceived relevance was one of the reasons for students’ lack of engagement in science. Hazari, Sonnert, Sadler, and Shanahan conversely found in a study of 3829 students that frequency of connections to everyday life in high school physics was significantly correlated with higher identification with physics and an increase in planning a career in physics [67]. If we can enable students to see how physics helps them to understand or to solve problems that they care about in their everyday lives, they are more motivated to learn and pursue physics.

Hazari et al. also showed that actively promoting real-world connections in physics may be important for promoting science identity for females in particular. In their study, females were significantly less likely to report that their high school physics class discussed currently relevant science topics, despite the fact the males and females in her study were in the same classrooms. This suggests that the science topics discussed were less relevant to the females, demonstrating the need and opportunity for identifying science that would be relevant to the females as well.
Another argument for real-world connections in physics can be made from the perspective of long-term scientific literacy. The recent National Science Education Standards emphasized scientific literacy as a key goal of science education, and understanding of connections between physics and real world issues is a key component of scientific literacy [68]. Understanding the connection between cultural, political, or social issues and scientific principles helps to inform people’s engagement with those issues and with the recommendations of scientists.

Considering these impacts on learning, transfer, retention, persistence, identity, and scientific literacy, it is unsurprising that researchers on students’ beliefs about physics have identified a belief in the intimate connection between physics and the real world as a key element of an expert-like attitude towards physics [13,54]. Learning to appreciate and make use of this relationship is one of the hallmarks of an expert physicist, and if we hope for our students to develop this expertise we must help them to learn to see the world and physics in this way. Studies using these same surveys of student beliefs shows a correlation between scores on these surveys and content learning, supporting the notion that helping students to connect between physics and the real world helps them to learn physics.

Within the Physics 100 Tutorials, I assume that if students are able to make use of their real-world knowledge within a physics class that this will have two benefits. Firstly I assume that the practice of using their everyday knowledge in conjunction with formal physics knowledge in a physics context constitutes a rehearsal for the practice of making use of these two kinds of knowledge in the everyday world, and will thereby improve students’ ability to apply physics knowledge outside the classroom. Secondly, I assume that making productive use of everyday knowledge in a physics context demonstrates to students the deep connection between physics and the everyday world, which will change their declared and implicit belief in the relevance of physics to the real world. These beliefs are important because they impact whether a student will even
think to make use of their formal physics knowledge in an everyday context. As Pugh, in his research on whether students make use of science outside the classroom, has said, “The ability to apply knowledge does not guarantee that students actually will apply their knowledge” [8].

I do not necessarily argue that each instance of a real-world connection will necessarily impact the students’ learning and beliefs about physics but rather that each is an opportunity for such an impact. In a similar manner to Sawtelle [69], who conducted moment-by-moment analysis to identify opportunities for students to develop self-efficacy, I argue that attending to and encouraging these real-world connections will create more opportunities to affect students’ learning and beliefs about physics and will have the effect over time of achieving the desired improvements.

6.2.2.3 Previous Work on Examining Students’ RWC

Making use of my earlier definition of Real-World Connections as students’ use of physics resources in the real world or vice versa, we can identify many other studies that have looked at students’ real-world connections from different perspectives. In this section I will describe some of these studies and some of their limitations that will be addressed in my thesis.

One method of examining students’ ability to apply scientific knowledge in the real world is by testing their performance on science questions that are contextualized in the real world [23,24]. In both of these studies, the researchers gave the students a test which included questions set in the real world where physics knowledge could be productively applied, and based on the results of those tests made claims about students’ abilities to make use of physics knowledge in a real world context. However these studies share the important limitation that students are likely to frame a paper-and-pencil test quite differently from an authentic engagement with a problem in the real world. As such, it is likely that the resources they apply to the test are substantially different from those they would apply in the real world.
Another approach to examining students’ use of science in their everyday lives is Pugh’s research on Transformative Experiences, which are defined as an instance of spontaneous use of science concepts in everyday experience in a way that changes the way a student sees the world [8]. He argues that students may engage in a variety of transformative experiences, ranging from meaningful engagement in the classroom on one end to intentionally seeking out examples of science concepts in their everyday lives on the other end [7]. This perspective is interesting in that it highlights the idea that a real-world connection need not occur in the physical context outside the classroom, but can be the product of students thinking about scientific and everyday ideas together.

Pugh’s research does not attend to the use of everyday knowledge in a scientific classroom. One limitation of this is that this research relies on measures of students’ transformative experiences via their responses to survey questions about what they do, think, and believe during their everyday lives. Such a survey is vulnerable to errors of poor student recollection, and is likely to record how students believe they act (or believe they ought to act) rather than their actual deeds, thoughts, and beliefs in that context.

One study which looks at students’ actual behavior rather than their test results or survey responses is Mayoh and Knutton who looked at the use of “out-of-school experience in science lessons” in 103 science lessons in British comprehensive schools [25]. This study looked for the use of “any experience or understanding arising outside formal classroom-based instruction” within students’ normal science classrooms. They examined both teachers’ and students’ references to the world outside the classroom, and compiled a taxonomy of different kinds of episodes where students or teachers mention out-of-school experiences during science lessons. While this research is illuminating, it was conducted in classrooms where teacher-mediated discourse was the norm: 69% of the episodes coded as involving out-of-school experiences had the teacher as one of the participants. Because I assume that it
is the students’ own connections that are meaningful to their learning and motivation, and because I have found that teachers’ and researchers’ ideas of what ought to be a real-world connection do not necessarily impact the students, I argue for a closer focus on the students.

Another thread of research that is relevant to the study is the wide variety of research into students’ intuitive understandings of science and the ways that they come into play in learning environments that has been conducted. (See [3] for an extensive list.) This research is motivated by the result that students’ intuitive knowledge and prior understandings impact whether and how they learn formal science content. While there are exceptions, this research is largely focused on how students’ real-world knowledge and intuitions affects their physics learning, and does not illuminate real-world connections that may impact students’ attitudes or identity. In order to address these dimensions of students’ experience in physics, a broader research focus is needed.

6.2.2.4 My Approach

The approach used in this study eschews the analysis of tests and surveys, and is instead focused on students’ discourse and behavior as they work collaboratively on problems where real-world resources can be productively applied. I try to include and identify Real-World Connections that are affective as well as cognitive, as I am interested in examining real-world connections that affect students’ identification with physics and their judgment of its relevance as well as their learning. The details of my methodology for coding students’ Real-World Connections are described in section 6.3.5 below.

6.2.3 Conceptual Discussion During Problem-Solving

The problem-solving strategy used in the Physics 100 recitations includes several steps that are explicitly intended to induce students to make use of their conceptual and qualitative knowledge both prior to and following their main calculations. Several published problem-solving strategies also include steps with the same intention [1,20,21].
According to Heller et al., context-rich problems were designed to “focus students’ attention on the need to use their conceptual knowledge of physics to qualitatively analyze a problem before beginning to manipulate equations” (p.629; All quotes in this paragraph from reference [1]). The structured problem-solving strategy that is recommended for use with these problems was designed to help students “integrate conceptual and procedural aspects of problem solving” (p. 628). This strategy requires students to “make a systematic series of translations of the problem into different representations, each in more abstract and mathematical detail” (p.628). For example, step 2 requires students to “use their qualitative understanding of physics concepts and principles to analyze and represent the problem in physics terms,” (p.629) explicitly directing students to perform a translation of representation from the narrative of the problem story into more formal physics abstractions.

The form of this strategy is informed by studies which focused on differences between how experts and novices solve problems [26,27]. A key finding of the expert-novice research is that experts are more likely to make use of qualitative reasoning before and after employing mathematical methods in solving physics problems. This ability to make use of qualitative knowledge has been identified as a crucial asset in successfully solving complex problems [70]. Experts were also seen to make more frequent use of specialized representations when solving problems. These results have motivated Heller and others to structure their problem-solving strategy around such translations of representation [20,21] and to explicitly encourage the use of qualitative knowledge before and after mathematical solutions. Many strategies enforce adherence to the expert-like strategy by requiring students to perform each step via a marking rubric or worksheet [1,20,21].

The use of such a strategy and the requirement that students follow each step implicitly assumes that the students will, in some meaningful way, follow the instructions laid out in each step. In the case of the above strategies, the requirement to develop an expert-like sequence of representations is intended to induce the students to perform the required tasks and presumably get better at developing representations and integrating conceptual knowledge by doing so.
Some research has borne out the merit of this approach. In a clinical setting, Dufresne et al. demonstrated that the use of a step-by-step computer guide to constrain novices to engage an expert like problem-solving behavior produced improved problem-solving performance [71].

However Heckler, working in a classroom setting, saw decreased performance as a result of explicitly prompting students to produce a free body diagram prior to solving a dynamics problem and suggests that this prompt “cued some students to the mindset that constructing the diagram and solving the problem are two separate tasks” [72]. His suggestion is that the use of prescribed problem-solving prompts may prime students to treat problem-solving steps as a list of instructions to follow rather than as individual elements that contribute to an overall understanding and coherent problem solution. In addition, Taconis’ meta-analysis of research on problem-solving methods concluded that “attention to knowledge of strategy and the practice of problem solving turned out to have little effect [on students’ acquisition of expert-like problem-solving skills],” suggesting that overall these structured methods may not be helpful in improving problem-solving performance [73]. Considering that structured problem-solving strategies are featured in many leading textbooks (e.g. [74,75]), the prospect that they may be ineffective is troubling.

In this study I do not examine the long-term effectiveness of these strategies at improving problem-solving performance or promoting development of problem-solving skills, but instead focus, via audio-recordings of their conversations, on students’ immediate interactions with the printed prompts that scaffold the prescribed strategy as they work through a problem. Given that these strategies are intended to induce students to make use of their conceptual knowledge at appropriate times during the problem-solving process, I examine students’ discussions to investigate whether these strategies are successful at doing so. In particular, I identify an epistemological frame where students’ discussions are aimed towards figuring out the meaning of the ideas under consideration, and examine each of the problem-solving steps to see when students engage in this frame.
6.3 Methodology

6.3.1 Overall Analysis Strategy

In order to address the above research questions I examine students’ discourse and behavior during their normal weekly recitation session and code them for three different types of information: instances when they encounter particular structured problem solving prompts on their worksheets, epistemological framing, and instances when they are making Real-World Connections. Coding is conducted by reviewing audio recordings of students’ discussion during recitation sessions, transcripts of these recordings, and (for approximately half of the episodes) field notes I took while sitting with the students as they work. In my analysis I attend to both the text and meaning of students’ speech as well as their turn-taking behavior, rhythm, and prosody of speech, after the tradition of conversation analysis [76, 77]. These characteristics offer insight into the substance of students’ ideas as well as into the ongoing negotiation of their framing of their activity [78, 79].

These codes are subsequently examined to reveal correlations between epistemological framing, problem-solving prompts, and Real-World Connections and to address the research questions. Figure 11 below serves as a map for the coding and analysis in this chapter and provides a reference to help locate the details of each coding scheme and correlation study.
Below I briefly discuss the role of Epistemological Framing in this analysis and describe the cohort and recruitment. Subsequently, I describe the three coding schemes in detail and illustrate these codes and correlations with particular examples of student dialogue. Then I describe the correlations observed between these codes and use analysis of selected episodes to develop and support causal arguments around the observed patterns of correlation.

Figure 11: Main coding schemes and correlation studies in Chapter 6.
6.3.1.1 On the Role of Epistemological Framing

As described in section 6.2.1 above, a person’s epistemological framing is their implicit sense of the nature of the activity they are engaged in with respect to knowledge and learning. In examining the different research questions in this study, the construct of framing is treated somewhat differently in different parts of the study.

In my examination of the Physics 100 recitations I will pay close attention to how students are framing their engagement with the problems in order to reveal how this framing correlates with their use of real-world knowledge. The Resources and Framing framework tells us that frames can increase or decrease the likelihood of activation of different sets of resources. Because I define Real-World Connections as activations of resources rooted in students’ lives outside the classroom, I consider their frames as being the structure that controls the likelihood of real-world connections. While recognizing that a real-world connection can induce a frame shift, for the purposes of this study I treat the frames as influencing Real-World Connections.

In my examination of the impact of problem solving prompts on the use of conceptual and qualitative information I will use epistemological frames to measure whether students are engaged in conceptual discussion with each other. In that study I treat the frames as being influenced by the structured problem-solving prompts.

6.3.1.2 Cohort

To examine students’ Real-World Connections in a typical physics context and their interaction with particular recitation features, this study focuses on in situ observations of groups of students collaborating in their regular weekly recitation sessions. The group nature of the recitation work requires the students to explain and negotiate with each other which helps to reveal their students’ thoughts and reactions to the recitation. As well, these peer interactions reveal their framing as they make use of meta-messages to coordinate their activity.
In an effort to get a cohort that represented the diversity of the student population, 14 different student groups were observed; one group per episode. The cohort for these studies was recruited in several different ways. Some of the student groups volunteered in response to in-class announcements. Because the groups that volunteered disproportionately represent the students that had high CLASS survey pre-scores, I was concerned that these students might tend to approach their recitations differently and therefore introduce a selection bias into the study.

In an effort to solicit broader representation of the student population, some groups were recruited by directly asking for participants during the recitation sessions. I would attend the recitation session, and before the normal introduction to the session would explain to the students that I was an education researcher and soliciting participants for a study in order to better understand how students react to the new recitations. I explained that participation was optional, anonymous, and would not impact their grades in any way and they would not be required to do anything out of the ordinary, nor would they be compensated for their participation. Then, while the TAs were giving their normal introduction to the recitation, I would look in the room to identify student groups that appeared attentive and engaged in the TAs speech and for student groups that appeared disinterested and/or disengaged. I would approach one group from each category after the TAs’ introduction and invite them to participate in the study. If any group members appeared uneasy or refused I would excuse myself and ask another group. In this fashion I attempted to record one group from each of the “attentive” and “disinterested” categories during each session that I visited.

Before commencing observation of a student group, I re-emphasized that the purpose of the research was merely to observe students’ normal activities and practices and would have no impact on their grades. In an attempt to minimize the disturbance to students’ normal interactions during the recitation session, I kept my body language separate from the group’s, and endeavored
not to engage students with my gaze or body language. I occasionally glanced at students directly in order to make note of their body language and gaze behavior.

A minimum of 4 student groups from each of recitations 7, 8, and 9 were recorded: half only with a simple audio recording device, and half audio-recorded while I sat with the students taking field notes. A total of 14 small-group recitation sessions were recorded. Each session was approximately an hour long and was transcribed for analysis. An individual session is referred to as an episode in the remainder of the dissertation. A subsection of a particular episode is referred to as a snippet.

6.3.2 Coding Problem-Solving Prompts

As described in section 2.4.4, students are required to use a prescribed problem-solving strategy in the Physics 100 recitations. This strategy lays out a series of 6 steps intended to lead students through an expert-like problem-solving process. This strategy is taught and used in lectures, and is also written on problem solving worksheets that are given out to each problem-solving group in the recitation. The worksheets have the problem written on the first page, and then each step is listed along with some notes elaborating what is expected for that problem-solving step. Below each step is an appropriate amount of whitespace for the students to write their work for that step. The steps and explanatory notes are quite general, and are the same from week to week.

Much of the research in constraining novices to use expert like problem-solving strategies focuses on requiring students to engage in “higher-level” thinking which is intended to enrich their procedural and mathematical treatment of physics problems by encouraging them to consider relevant conceptual and qualitative knowledge such as physics concepts, the narrative of the problem, and their common sense. In developing this problem-solving method, the Physics 100 instructors and I expected that the descriptive prompts for steps 1, 2, 3, and 6 would encourage students to make use of their conceptual and qualitative information.
To enable me to examine the correlations between the prompts and students’ use of conceptual or real-world knowledge, I coded the transcripts to determine when students reached each step of the prescribed problem-solving method. Often, when reaching a new step students would either read that prompt out loud or make a direct comment about “what we have to do next”. In circumstances where the timing of reaching a particular step could not be determined, the discourse in that prompt was excluded from my analysis. Coding of the prompts was verified by two researchers who coded three different transcripts independently with 100% inter-rater reliability. The remainder of the prompts were coded by a single researcher.

Note that I do not code what kind of problem-solving activity the students are engaged in, but simply note the time when they reach the printed problem-solving prompts on their worksheet. Because the goal of this study is to examine how students react to the pedagogical structure of the prescribed problem-solving strategy, I am interested in how they respond to these prompts.

6.3.3 Validation of Audio-Only Coding of Epistemological Framing

To code epistemological framing for an interacting group of students throughout the recitation episode I used a modified version of a coding scheme developed by Scherr and Hammer [64]. Rather than use video analysis, as was used by Scherr and Hammer, I reasoned that it would be preferable to conduct framing analysis on audio data for my research. Audio data is much cheaper and easier to gather and engenders fewer ethics concerns regarding the participants’ anonymity. In order to investigate whether behavior-based epistemological framing coding could be conducted without the aid of video, I collaborated with Dr. Scherr to compare the results of two different researchers coding the same data but using different media modalities. One researcher coded audio and video together, and the second researcher coded audio only. In addition to validating the methodology used for my thesis, we reasoned that a proof of concept for audio analysis of framing might open up this research methodology to a wider variety of researchers.
6.3.3.1 Data

In order to investigate the correlation between audio-only and video coding, Dr. Rachel Scherr and I coded four different episodes. Three of the episodes were videos upon which the original Scherr and Hammer paper had been based. The fourth episode was an audio-only episode from the Physics 100 recitations. These episodes are summarized in Table 19 below.

<table>
<thead>
<tr>
<th>Episode</th>
<th>Rachel Coded</th>
<th>Sandy Coded</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Audio</td>
<td>Audio</td>
<td>To educate Rachel about audio-only coding, so we could discuss the relative benefits of each medium</td>
</tr>
<tr>
<td>2</td>
<td>Video</td>
<td>Video</td>
<td>To train Sandy in Rachel’s coding scheme; to replicate original result</td>
</tr>
<tr>
<td>3</td>
<td>Video</td>
<td>Audio</td>
<td>To compare relative merits and reliability of audio-only vs. video</td>
</tr>
<tr>
<td>4</td>
<td>Video</td>
<td>Audio</td>
<td></td>
</tr>
</tbody>
</table>

Table 19: Summary of audio and video episodes coded for validation of audio-only coding of epistemological framing.

6.3.3.2 Methodology

All four episodes were coded using the Scherr and Hammer coding scheme, which described in section 6.2.1.1 above.

Both researchers coded the audio episode in order to investigate the limitations of audio-only coding. One of the video episodes was coded by both researchers using the full video data in order to conduct a replication study of the original Scherr and Hammer result and to ensure that I was trained to use this coding scheme in the same fashion as the researchers that coded for the original paper. The two remaining video episodes were coded by me using audio only. This coding was compared to the audio and video coding that was used in the original Scherr and Hammer study.

To code epistemological framing using audio signals we made use of the audible behavior described in the original Scherr and Hammer paper, as well as identifying some additional audio cues that could indicate student behavior. Below I will review the audible signals that we associated with each frame.
**BLUE: WORKSHEET FRAME**

In this frame students’ primary concern is getting things down on the worksheet. In many cases this means the students do not speak, and the audio is silent or faint scribbling of pens or flipping of pages can be heard. It was assumed that any long period of silence with on-task discussion bracketing it indicated the students were in the Blue frame.

In this frame students may also “check in” with each other in order to verify something that they are about to write down. These verbalizations are usually fairly short and consist of one or two brief question-and-answer exchanges. The vocal pitch is not dynamic, and tends towards monotone or simple rising and falling tones to indicate questions and answers. These check-ins are typically bracketed by silence.

The silences between exchanges is a key indicator that the students’ attention is not fully focused on having a discussion with each other. In a recitation context, if the bracketing discussion is on-task, we assume that in the intervening silences the students are still attending to the problem worksheet.

Another vocal signal that indicates the worksheet frame is speaking slowly with elongated vowel sounds and/or long pauses between words. This indicates that the speaker is writing, and is speaking aloud at the same tempo as their writing. This behavior of writing may also be accompanied by muttering in a barely audible way.

**GREEN: DISCUSSION FRAME**

In the Green frame students speak clearly. Their voices are loud enough to be clearly heard by their peers, and enunciation is crisp enough to be understood.

The rhythm of speech is more rapid. Statements may be longer and more elaborated than in the Blue frame, but responses come very quickly. There are typically very few noticeable pauses between one student’s statement and
another’s response, and students sometimes interrupt each other or finish each others’ sentences.

The pitch of the voice is more dynamic. As students argue and reason with each other their vocal pitch may change in ways more complex than the simple question and answer patterns observed in the Blue frame.

One of the more important ways to distinguish between Blue frame (Worksheet) and Green frame (Discussion) is the speed with which students respond to each other in conversation. In the Green frame students’ responses are very rapid, sometimes even interrupting each other with a new idea or finishing each others’ sentences.

**RED: TA FRAME**

In this frame students’ attention is on the TA. From the audio data it is impossible to tell where the students are looking, so we assume that they are in the Red frame whenever the TA is present at the table or whenever the TA is speaking to the entire class.

**YELLOW: JOKING FRAME**

To code the audio for this frame we look for students using a joking or sarcastic tone of voice. Students in this frame may exaggerate the normal variation in pitch. A joking remark may be followed up with several more. Laughter is also an indicator of this category.

**6.3.3.3 Results**

After both researchers had coded each episode their codes were compared. As in Scherr and Hammer’s original study, frame transitions that were within 5 seconds of each other were considered to be the same within a reasonable margin of error, and were therefore not counted towards the total amount of error. Any other mismatches were counted as errors, and the final inter-rater
reliability was calculated as $\text{IRR} = 1 - (\text{errors}) / (\text{total duration})$. The results of this comparison are summarized in Table 20 below.

<table>
<thead>
<tr>
<th>Episode</th>
<th>Coding Type</th>
<th>Duration (sec)</th>
<th>Errors (sec)</th>
<th>IRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A/A</td>
<td>1515</td>
<td>155</td>
<td>90%</td>
</tr>
<tr>
<td>2</td>
<td>V/V</td>
<td>1870</td>
<td>190</td>
<td>90%</td>
</tr>
<tr>
<td>3</td>
<td>A/V</td>
<td>1425</td>
<td>235</td>
<td>84%</td>
</tr>
<tr>
<td>4</td>
<td>A/V</td>
<td>3010</td>
<td>525</td>
<td>83%</td>
</tr>
</tbody>
</table>

Table 20: Inter-rater reliability for study of audio-only vs. video coding of epistemological framing. Frame transitions were coded to within 5 second accuracy. The inter-rater reliability was calculated as $\text{IRR} = 1 - (\text{errors}) / (\text{total duration coded})$.

As shown in Table 20, all episodes were coded with greater than 80% inter-rater reliability. This suggests that much of the framing information that is coded in body language is also present in gestural characteristics of the voice. More attention must be paid to the specific rhythm and characteristics of the voice, but by attending to pitch, rhythm, speed of reply, turn-taking in conversation, and other aspects of prosody students’ expectations about communication and collaboration are revealed.

Although the sample sizes are obviously very small, it is interesting to note that the highest inter-rater reliability occurs when both coders are using the same media type.

In order to investigate the cause of the errors, the 17% of time where the coders disagreed on episode 4 was discussed in order to determine the reason for this agreement. A total of seven main categories accounted for 84% of the disagreement, and these seven categories could be broken up into 2 main themes: issues with the audio only methodology, and refinements or corrections to the original coding. The breakdown of these errors is depicted in Figure 12 below.
Figure 12: Summary of reasons for inter-coder error when coding epistemological framing with audio only vs. audio plus video.

6.3.3.4 Limitations of Audio-Only Coding for Epistemological Framing

As shown in Figure 12, 42% of the errors were due to issues with the audio methodology. These errors highlighted weaknesses of using audio only in order to perform a behavioral coding. For example 13% of the errors were due to circumstances where the students gave unambiguous body language cues but their audio cues were ambiguous. An example of this was when one student was speaking very clearly about his ideas without interruption or elaboration from his peers. The lack of audible interaction does not give any information about the actions of the other group members, but their silence suggested they were paying attention to their peer’s speech. However the video showed clearly that the other group members were not paying attention and were instead focusing on their worksheets.
Another type of issue with coding using audio only arises when students’ speech and behavior explicitly give different signals. An example of this is when students are speaking clearly to each other while keeping her body language oriented towards the worksheets. Their clear speech indicates to the audio coder that the students are engaged in discussion with each other, but their attention to the worksheet and static body language indicates to the video coder that they are focused on the worksheet.

The third category of problems with using audio only for coding of epistemological framing is that it is impossible to distinguish whether students are paying attention to the TA when the TA is physically present. There were several instances where students became so engaged in a conversation with each other while the TA was present that the video researcher coded their conversation as Discussion rather than as Paying Attention To The TA. However there are no discernible audio cues for when this occurs and so the audio–only coder has no choice but to code the TA frame for the entire duration of the TA’s presence at the table.

Finally, there is an important difference between the two coders’ ability to detect a group’s transition into a new frame. When one has access to the video record of the student body language, one can easily tell when the students are paying attention to each other. This makes it easy to tell when a particular student's bid for frame change has been taken up by his or her colleagues: their attention to the new idea will be apparent. However when one is coding audio only, one must wait for some verbal evidence that a student’s peers have begun paying attention to his or her idea. The necessity of waiting for a verbal cue to indicate a group’s subscription to a new frame leads to small differences in when frame transitions are coded by the audio–only coder versus the audio plus video coder.

6.3.3.5 Comments on Scherr and Hammer's Original Coding

The comparison of the two coding methods also revealed some issues with the original coding. Firstly, upon comparison and discussion of some of the
coding errors Dr. Scherr agreed that some of the video codes that had been assigned during her original research did not match with the coding scheme as described in the paper. As such, when I coded the audio according to the published coding scheme, the code that I assigned was different than the code assigned during her original research.

Secondly, despite the original paper’s claim that the coding was based on students’ behavior alone, it was revealed that some of the original codes were made based on the content of student speech. This coding based on content added additional insight into how the students were framing the current situation, but violated Scherr and Hammer’s claim that their methodology used only the behavioral characteristics of speech and body language in order to assign an epistemological frame code. In these cases the consideration of the content of students’ speech led to a different code being applied, which was later revealed as a difference between the two coders’ results.

Finally, a re-examination of the disagreements between the two coders showed one instance where the students’ behavior did not fit cleanly into one of Scherr and Hammer’s four categories. The students engaged in a protracted, thoughtful, dynamic discussion [Green frame] that was completely concerned with and directed towards the worksheet [Blue frame]. This behavior was clearly a mixture of the two frames listed by Scherr and Hammer.

6.3.3.6 Summary

An investigation of the inter-rater reliability between one rater who coded epistemological framing using audio only and another rater who coded using both audio and video showed that these raters coded the same epistemological frame more than 80% of the time.

While there are some weaknesses of using audio only for this purpose, this high reliability leads me to conclude that audio gives sufficient information to code students’ epistemological framing.
6.3.4 Development of Epistemological Framing Coding Scheme

In addition to coding via audio-only, I also modified the Scherr and Hammer coding scheme in two ways. This coding scheme was adapted for suitability to my particular context and students, and was refined by using examination of the implicit goal of students’ discussion to identify two different epistemological frames that occur during discussion.

In the following sections I describe the adaptation of the Scherr and Hammer scheme and the new frames that were particular to this context. Then I summarize the final scheme and give some representative coding examples, describe the inter-rater reliability study used to refine the scheme, and discuss the limitations of this coding methodology.

6.3.4.1 Adaptation to Cohort

For their study of behavior and epistemological framing in group problem solving, Scherr and Hammer pre-selected the groups to study based on which ones talked to each other frequently and were consistently on task. By their own description, this represents a best-case scenario.

While this methodology seems appropriate for an exploratory study aimed at identifying different categories of students’ frames, my aim is slightly different. I want to make arguments about correlations between frames, features of the recitation structure, and students' thinking. Therefore I have endeavored to gather data from a broader variety of student groups. Indeed, in order to avoid analyzing only the "best case," I deliberately solicited the participation of students that seemed disengaged in the recitation format in addition to students that volunteered and expressed positive opinions of the recitation and the course. As well, some of the groups studied did not interact with each other in an ideal interactive and collaborative fashion. The hope is that this special attention to recruiting a broad variety of student groups will yield results that are more representative of the student population as a whole.
Another important extension of the Scherr and Hammer coding scheme was the splitting of their Discussion frame into two subcategories. These two categories arose from going beyond behavior-only coding to consider the content of the students’ speech. Specifically, when considering the transcripts I noticed that there were two broad goals that motivated students in their discussions: understanding of the current ideas or figuring out how to make progress towards a solution. As discussed below, these different goals are evidenced by students’ speech and have an influence on their behavior in the recitation as they try to achieve their goal. Because these two goals represent an important distinction in the students’ sense of the essential nature of their current activity and because these different goals have different implications for how students negotiate and develop knowledge, I argue that they distinguish two different epistemological frames. The goal of understanding of the current ideas corresponds with a frame I have labeled Conceptual Discussion (CD), and the goal of figuring out how to make progress towards a solution corresponds with a frame labeled Procedural Discussion (PD).

Unlike the changes in behavioral clusters marked by Scherr and Hammer, the switch between Conceptual Discussion and Procedural Discussion cannot necessarily be distinguished by changes in tone, rhythm, or register. In the tradition of Tannen, I make my arguments about the existence of these frames based on the substance of speech as well as linguistic markers associated with speech acts [63].

To flesh out our description of these frames, I will show snippets of transcript where students’ implicit goals are clear. Then I will describe the markers of the frames used in my coding scheme and compare and contrast these frames to each other and to Scherr and Hammer’s frame. Throughout these descriptions I will be sharing my interpretations of students’ goals and meta-messages, interpretations that I believe rest on a shared cultural language of framing communication which I expect that I share with many of my subjects.
and readers. I hope that my readers will agree with my analysis of these quotes, supporting my interpretations.

**Conceptual Discussion**

Some student discussions are clearly oriented towards interpreting the meaning of the problem, building an understanding of the physics, or developing a coherent narrative or visualization of the situation under consideration. This frame is where we see students striving to express, understand, and synthesize new ideas. This frame has the implicit goal of “figuring out what is going on,” and is called the Conceptual Discussion (CD) frame.

The following example illustrates this frame. A group of students has just read a recitation problem which centers around the force in ropes that are restraining a fridge in the back of a pickup truck. (See page 316 in Appendix A for the full problem) The transcript begins with Student 2 asking a question after a long period of silence, during which the group has read the recitation problem.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mary</td>
<td>But if there's 2 of the straps does that mean you can double the force?</td>
</tr>
<tr>
<td>2</td>
<td>Natasha</td>
<td>Are there 2 ropes or 1 rope?</td>
</tr>
<tr>
<td>3</td>
<td>Leah</td>
<td>There's 2 right?</td>
</tr>
<tr>
<td>4</td>
<td>Natasha</td>
<td>2 ropes?</td>
</tr>
<tr>
<td>5</td>
<td>Mary</td>
<td>I don't know</td>
</tr>
<tr>
<td>6</td>
<td>Natasha</td>
<td>Or it's the same rope and it's (mumbling)</td>
</tr>
<tr>
<td>7</td>
<td>Mary</td>
<td>If it's like each rope takes half that</td>
</tr>
<tr>
<td>8</td>
<td>Leah</td>
<td>Oh like that, yeah. I think that would make sense, because it said that it was tied at the back, so that doesn't make a lot of sense</td>
</tr>
<tr>
<td>9</td>
<td>Mary</td>
<td>No</td>
</tr>
</tbody>
</table>

*Table 21: Example of Conceptual Discussion. The students’ focus is on figuring out what is going on in the situation and the implications for the force in the rope.*
In this episode, the students are trying to visualize the configuration of ropes that hold the fridge in the truck. The episode begins with Mary asking about the number of straps as well as the implications for the force on the fridge. Her question on line 1 clearly targets the conceptual relationship between the number of ropes and the force in each rope.

In the subsequent dialogue the students discuss different possibilities for the configuration of ropes. Leah’s comment on line 8 demonstrates that she is evaluating these possibilities in terms of “what makes sense.” This implies that Leah’s implicit goal in this conversation is constructing a picture of the truck, ropes, and fridge that meets his expectations about sensible arrangements of trucks, ropes, and fridges.

It is interesting that, on the surface, that Mary and Leah are focused on different aspects of the problem. Mary is focused on how the two ropes would double the force, whereas Leah is trying to work out a sensible visualization of the problem. However, both are engaged in trying to interpret the meaning of the problem by coordinating it with their conceptual understandings and expectations about the world, and in that sense share an epistemological frame. This shared focus on determining “what makes sense” is indicated by Mary’s response on line 9, which is delivered immediately after Leah’s statement and with a tone of affirmation. By this immediate response Mary indicates her agreement with Leah and also implies that she believes that discussing “what makes sense” is the appropriate activity in this moment. This immediate, implicit agreement implies that Mary and Leah are sharing the same frame.

Not every instance of students interpreting a problem statement can be considered Conceptual Discussion. Many such instances involve students working to understand what the professor is asking without considering their own judgments of what kinds of physical systems and configurations would be meaningfully coherent. However, the students in this transcript are engaged in developing a coherent visualization and understanding the force in the ropes in ways that foreground their own conceptual knowledge and sense of real-world
plausibility. While these students will turn their attention to the requirements of the problem shortly, in this moment they are more concerned with their own requirements for a coherent picture that makes sense to them. This shared focus on trying to develop a coherent and meaningful visualization is an excellent example of “figuring out what is happening,” and therefore a good example of the Conceptual Discussion frame.

PROCEDURAL DISCUSSION

At other times students’ discussions are clearly oriented towards figuring out what to do in order to make progress. In this case, “progress” is defined in terms of the external or formal requirements such as the instructions on the worksheet, perceived expectations of the professor, or completion of mathematical calculations. Students may discuss and reason with each other in order to choose a course of action, but their warrants are drawn from either a sense of what they “should do” next (referencing the external authority of the professor or worksheet) or from a sense of mathematical convenience rather than reasoning based on what makes sense to them. This frame is identified by the implicit goal of “figuring out what to do,” and is therefore called the Procedural Discussion (PD) frame.

The notion of discussion that is not oriented towards physics concepts marks a significant distinction from the Scherr and Hammer scheme, which claims that when engaged in discussion students are always discussing each other's ideas. Based on my observations of the content of student speech in the Physics 100 recitations, I claim that students can be engaged with each other in discussion of how to proceed in the problem. My observations have shown that these discussions exhibit authentic responsiveness to each others’ ideas and dynamic vocal register (hallmarks of the Scherr and Hammer Discussion frame) but are focused on procedural rather than conceptual matters.

The Procedural Discussion frame also borrows some of the characteristics of the Scherr and Hammer Worksheet frame. Students in the Procedural
Discussion frame are often concerned with how to satisfy the professor's requirements or to get the marks on the recitation worksheet, characteristics which Scherr and Hammer associate with their Worksheet frame. However, the characteristics of students’ speech in the Procedural Discussion frame are dynamic and interactive, characteristics associated with Scherr and Hammer’s Discussion frame, which they claim indicates that the students are framing their activity as *figuring something out*.

Based on their dynamic speech behavior, I contend that the Procedural Discussion frame is essentially understood by the students as a Discussion. In this case, the thing that they are figuring out is a strategy, a plan for their calculation, the requirements of the professor or the worksheet, or anything else that will help them proceed towards the goal of completing worksheet.

The similarities between my Procedural Discussion frame and the Scherr and Hammer Worksheet frame raise the question of whether Procedural Discussion ought to simply be coded in the Worksheet category. Based on in-class observations that students are looking at each other during Procedural Discussion frames, I would argue that this frame is distinct from the Worksheet frame, where students’ attention is directed to the worksheet itself. As well, the dynamic tone of voice and rapid, responsive conversation are much more like the behaviors associated with discussion than the low register, monotone, clipped, or broken speech associated with the Worksheet frame. In my scheme, the Worksheet frame is reserved for the doing of the worksheet: the immediate business of executing the group’s plan, conducting calculations, and/or writing down the results.

The transcript below shows an example of a Procedural Discussion frame. This transcript is drawn from a different group working on the same problem as above. As above, this transcript begins just as students have finished reading the recitation problem which centers around the force in ropes that are restraining a fridge in the back of a pickup truck. (See page 316 in Appendix A for the full problem)
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Igor</td>
<td>So the second paragraph says you don't want the hitch to come loose and smash, so basically if it's there, and you have a collision you'd be like, whooop</td>
</tr>
<tr>
<td>2</td>
<td>Winifred</td>
<td>ok</td>
</tr>
<tr>
<td>3</td>
<td>Unknown</td>
<td>(Background noise, pages turning)</td>
</tr>
<tr>
<td>4</td>
<td>Igor</td>
<td>Yep, so we're calculating the deceleration</td>
</tr>
<tr>
<td>5</td>
<td>Denise</td>
<td>Umm, well we're calculating the force exerted on the fridge by deceleration</td>
</tr>
<tr>
<td>6</td>
<td>Igor</td>
<td>Yep, and if it will exceed the maximum like 750N? You know, pretty, straightforward</td>
</tr>
<tr>
<td>7</td>
<td>Winifred</td>
<td>So I guess our goal is to determine whether the deceleration force is greater than or less than - the deceleration force exerted on the fridge - is less than or equal to 750N?</td>
</tr>
<tr>
<td>8</td>
<td>Igor</td>
<td>Yeah</td>
</tr>
<tr>
<td>9</td>
<td>Winifred</td>
<td>Is that right?</td>
</tr>
<tr>
<td>10</td>
<td>Denise</td>
<td>I think so (pauses)</td>
</tr>
<tr>
<td>11</td>
<td>Winifred</td>
<td>I'm not exactly sure how we would calculate that</td>
</tr>
<tr>
<td>12</td>
<td>Igor</td>
<td>Well we don't really need to know the truck's mass do we?</td>
</tr>
<tr>
<td>13</td>
<td>Denise</td>
<td>(interrupting) For the force?</td>
</tr>
<tr>
<td>14</td>
<td>Igor</td>
<td>Or no, we do, for the acceleration</td>
</tr>
<tr>
<td>15</td>
<td>Winifred</td>
<td>No, I think all we need to know is, um, I think we can use like v_1, v_final, acceleration, distance, cause we know the distance and then we know v_initial and v_final, we could find the deceleration, and then we can find the deceleration in terms of g, right? (pause) um, which, multiplied by the kilograms of the fridge is going to give the number of Newtons? Is that right?</td>
</tr>
</tbody>
</table>

Table 22: Example of Procedural Discussion. The students’ focus is on figuring out what they should be calculating.

The transcript begins with Igor’s interpretation of the goal of the problem, which is to ensure that a fridge is tied down adequately so that it wouldn’t come loose in an accident. This interpretation is quite qualitative and conceptual, but does not elicit much response from the group except for a simple “ok” from Winifred. In the next statement on line 4 Igor announces “what we’re doing,” an implicit way of soliciting his group’s consensus for his proposed plan. His conception of “what we’re doing” is completely concerned
with the result of a calculation, an approach which is reinforced by the
contributions of Denise on line 5 who discusses what “we’re calculating,” and
by Winifred on line 7 who describes that their goal is to determine the
mathematical magnitude of a certain force. Throughout the remainder of this
transcript the students’ conversation is limited to discussion of what should be
calculated and how it ought to be calculated.

In this segment the students respond to each others’ ideas, follow a thread
of conversation, and communicate with each other in clear, dynamic voices
that indicate they expect to be heard by their peers. These behaviors display
the students’ framing as having a discussion, but the discussion is centered
tightly around the perceived requirements of the worksheet and calculation.
In order to address those requirements, the students access their knowledge
about calculations, a very different set of resources from the students in the
same situation above who discuss physical configurations, objects, and
relationships.

This illustrates how the implicit goal of figuring out what to do describes a
distinct frame that has different implications for what kinds of knowledge and
actions students are likely to see as fruitful. Therefore, defining the distinct
Procedural Discussion frame is both necessary and justified.

The addition of a distinctive Procedural Discussion frame raises the
question of why Scherr and Hammer did not observe a similar cluster of
behaviors in their study. I hypothesize that this type of engaged-discussion-
about-procedure might be more necessary in our context than in theirs due to
the fact that students in Physics 100 have only one worksheet to fill out rather
than each student working on their own worksheet. This places a higher
premium on group consensus, which would require students to interact and
look at each other more closely even when they are discussing seemingly
mundane strategic questions. As well, our context-rich recitations place a
much larger onus on the students to interpret the problem and plan their own
solution than the highly-scaffolded tutorials used in the Scherr and Hammer
study. This might serve to further increase the need for students to explicitly develop and discuss their solution strategy, increasing the need for Procedural Discussion. Finally, the type of tasks given in Scherr and Hammer’s tutorials do not require students to perform extended calculations. Therefore, protracted discussions of problem-solving strategy may have been simply unnecessary.

**Comparison of Conceptual and Procedural Discussion**

Over the course of coding the wide variety of transcripts for this project those two organizing principles of “figuring out what to do” and “figuring out what is going on” have formed the core identity of the Procedural Discussion and Conceptual Discussion frames. The students’ focus on one or the other of these goals is evidenced by the warrants they use in arguments, their use of mathematics, the way they attend to the description and instructions written on the recitation sheet, as well as direct references to procedure, planning, and meaning. Table 23 summarizes some of the characteristics of these two frames.
<table>
<thead>
<tr>
<th><strong>PD: Procedural Discussion.</strong></th>
<th><strong>CD: Conceptual Discussion.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Goal</strong></td>
<td><strong>GOAL is to make progress towards the answer of the worksheet. Interpreting what the instructor / worksheet is asking for. Satisfying the different steps of the process. Getting an answer on the page</strong></td>
</tr>
<tr>
<td><strong>Focused on</strong></td>
<td><strong>GOAL is to interpret / understand what's going on. Students want to satisfy their own sense of what is sensible / reasonable.</strong></td>
</tr>
<tr>
<td><strong>Example Activities and Quotes</strong></td>
<td>Focused on understanding the physics of what’s happening</td>
</tr>
<tr>
<td><strong>Discussion of strategy – “what do we do next?” , “we can do X or Y”</strong></td>
<td>Coordination of representation from narrative -&gt; mathematical “Vf is zero because it stops”</td>
</tr>
<tr>
<td><strong>Discussion of “what we’re supposed to do” , “should”, “what do we need to do”</strong></td>
<td>Seeking to understand meaning of physics concepts ”How can it be both constant acceleration and velocity both?”</td>
</tr>
<tr>
<td><strong>“What we’re calculating”</strong></td>
<td>Reference to students’ own intuition or commonsense ”that would make a lot of sense”</td>
</tr>
<tr>
<td><strong>Review of Problem</strong></td>
<td><strong>Paraphrasing and / or interpreting given problem in order to identify knowns &amp; unknowns</strong></td>
</tr>
<tr>
<td><strong>Conceptual interpretation of the given problem / situation</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Discussion of Assumptions</strong></td>
<td><strong>Discussion of assumptions framed as a list of things to satisfy worksheet condition</strong></td>
</tr>
<tr>
<td><strong>Interpretation of assumptions framed as what makes sense.</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Interpretation of Mathematics</strong></td>
<td><strong>Interpretation of consistency of mathematics</strong></td>
</tr>
<tr>
<td><strong>Interpretation of MEANING of mathematics, or MEANING / concept / Narrative of what’s happening in the question</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Conceptual interpretation of mathematical structure. “This part is the heat in, and this part is the heat out”</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Evaluation of Results</strong></td>
<td><strong>Evaluation of result by “looking at the big picture”</strong></td>
</tr>
<tr>
<td><strong>Evaluation of results that is brief, shallow, parrots prior work / authority.</strong></td>
<td><strong>Evaluation of results in terms of qualitative / conceptual understanding of the result.</strong></td>
</tr>
<tr>
<td><strong>Evaluation of results in terms of algebraic consistency</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 23: Characteristics of Procedural Discussion and Conceptual Discussion frames.

6.3.4.3 Differences in Worksheet Frame

Scherr and Hammer’s Worksheet frame is characterized by an immediate focus on recording things on the worksheet. When conducting video analysis,
this is evidenced clearly by body language oriented towards the worksheet. However in audio we must pay attention to different characteristics in order to infer the object of students’ attention.

The first cluster of audible behaviors that indicates a focus on the worksheet is when the students are engaged in writing or calculation. In the best case, one can hear the sound of pencil scratch on paper while the group is writing silently. Direct observations have confirmed that a period of silence bracketed by on-task discussion means that somebody is conducting a calculation or writing something down. While writing or calculating students may mutter to themselves or recite what they are writing. Students that are reciting as they write will have a noticeably slowed pace of speech with pauses in between each word that regulate the speech to the same pace as writing. In normal conversation these pauses would be unnecessary and perhaps annoying but when recording what one presumes is the consensus of a collaborative group, this recitation serves as a last chance to ensure the group's consensus on what is to be written.

In my analysis, I found a second main category of behavior that corresponds to a focus on the worksheet. The second cluster of behavior that occurs in the worksheet frame is when one student is writing and one or more students are directing them what to write. A student will sometimes feel it is necessary to closely monitor and/or directly control what is being written on the page even though they are not the person with the pen. In these circumstances the audio recording will show a steady stream of direct instructions to the person writing. Typical behaviors that indicate this is occurring are: the person directing speaking very slowly, pronouncing syllables individually, pronouncing punctuation marks, repeating themselves, or offering explicit imperative directions such as “write X squared”. While these speech acts may have very clear diction and are clearly intended as communication, their imperative nature demonstrates that they are instructions to another person and are intended to directly influence what is being written. This focus on the writing
on the page indicates that the students engaged in this behavioral cluster are also focused on completing the worksheet. Therefore, this cluster is subsumed into our definition of the Worksheet frame.

This behavioral cluster is absent from the Scherr and Hammer data, likely due to the fact that in their study each student has their own copy of the worksheet.

6.3.4.4 Comparison of Procedural Discussion and Worksheet Frame

One might argue that the Procedural Discussion and Worksheet frame, while behaviorally different, are both concerned with the same epistemological activity of generating answers to the worksheet questions. There are certainly many similarities in this regard. In both frames, the students’ conceptual understandings take a backseat to their focus on understanding and meeting the perceived requirements of the problem. However, there is an important difference between these two frames that supports my practice of treating them separately. In the Procedural Discussion frame, the students are engaged with each other in the process of figuring out what to do. That is, they are developing a strategy for meeting their perception of the goals of the worksheet. Conversely, in the Worksheet frame, the students are executing their strategy. The relative paucity of conversation reveals their belief-in-the-moment that no more discussion or negotiation is required in order to determine what to do next; all that is required is the execution of the previously-agreed-upon plan.

It is interesting to see these two frames interleave with each other during the problem-solving process. Students will develop a plan, begin executing it, and then when either a result is obtained or an unanticipated barrier is encountered, they will return to Procedural Discussion in order to figure out what to do next. This pattern recalls Goffman’s notion of “nested frames” [80], in the local “develop a strategy to get the answer” frame as well as the “execute the strategy and record the results” frame may be nested in an overarching “complete the worksheet” frame. Procedural Discussion and Worksheet frames may both be oriented towards the overall goal of completing the worksheet, but
their different orientation towards developing vs. executing the solution strategy come with different epistemological commitments, and are therefore appropriately classified as different epistemological frames.

6.3.4.5 Other New Frames

Due to particular features of our instructional context and research goals, two other distinct frames were identified. The first of the special frames deals with behaviors that do not fit into any of our other frames and that we felt were important to our goal of exploring how students make connections between their everyday knowledge and the recitation problem. In this frame, students comment on and criticize the ostensible connections between the problem and the everyday world. This may take the form of praise or complaints about the perceived realism of the problem situation itself. Because these speech acts are not focused on completing the problem or understanding the physics concepts that are promoted by the problem, they do not fit into either the Procedural Discussion or Conceptual Discussion frames. In order to reflect the students' understanding of these situations, and also to mark what we believe are important moments of connection between the recitation and the real world, these conversations are marked with the “Meta-Comment” frame.

The second special frame arises as a result of our use of the prescribed group roles recommended by Heller et. al for use with their context-rich problems [1]. Students are assigned a different role each week, and may be required to act as the group's manager, recorder, skeptic, or explainer. As such, a certain amount of the students' discussion revolves around assignment and duties of various group roles. These discussions are clearly identifiable but do not fit into any of our other frames and so we identify them with the “Group Role Negotiation” frame.
6.3.4.6 Summary of Framing Coding Scheme

The set of epistemological frames used for this study is listed in the table below. The full coding guide and rubric that were used for coding epistemological framing is listed in appendix D.

<table>
<thead>
<tr>
<th>Frame</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual Discussion</td>
<td>CD</td>
<td>Engaged discussion to make sense of the narrative of the problem or meaning of the physics</td>
</tr>
<tr>
<td>Procedural Discussion</td>
<td>PD</td>
<td>Engaged discussion to figure out how to proceed or what the professor expects</td>
</tr>
<tr>
<td>Worksheet</td>
<td>W</td>
<td>Focus on writing on worksheet or directing others' writing</td>
</tr>
<tr>
<td>TA focus</td>
<td>TA</td>
<td>Focus on interacting with the TA</td>
</tr>
<tr>
<td>Group Negotiation</td>
<td>G</td>
<td>Focus on interpreting or reinforcing assigned group roles</td>
</tr>
<tr>
<td>Meta-comments</td>
<td>M</td>
<td>Focus on discussing (un)realism of provided tutorial problem</td>
</tr>
<tr>
<td>Other / Off-topic</td>
<td>O</td>
<td>joking, discussion not having to do with tutorial</td>
</tr>
</tbody>
</table>

Table 24: Summary of epistemological framing coding scheme.

Typically, coding is done in two passes over the audio recording. In the first pass, the students' tone, rhythm, and prosody are used to make the main distinctions between Worksheet frame, TA frame, Off-topic frame, and Discussion. Then the coder will make a second pass through the areas marked Discussion paying close attention to the content of students' speech. The details of exactly what students are saying and implying are used to distinguish between Conceptual Discussion, Procedural Discussion, Group role negotiation, or Meta-comments.

6.3.4.7 Example of Framing Coding

The following example demonstrates the Procedural Discussion, Conceptual Discussion, Worksheet, and Off-Topic frames as well as several frame transitions. These frame transitions help to illustrate the frames by contrasting them against each other. In this transcript a group of students are
working on a problem that concerns calculating the force on a passenger during normal braking and also during a crash. Prior to the beginning of this transcript the students have been instructed to “Define Assumptions and Relationships,” one of the standard steps in the prescribed problems solving method used in the Physics 100 recitation questions. (See section 2.4.4 for more details on this problem-solving method.) The students have already been discussing their assumptions for several minutes. The transcript begins as S4 brings the group’s attention back to this task after a short period of off-topic discussion.
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Michael</td>
<td>Ok, what else? Well, we assumed that, um (pause) no airbag.</td>
<td>1</td>
<td>W</td>
</tr>
<tr>
<td>2</td>
<td>Gordon</td>
<td>All right</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Isaac</td>
<td>Isaac: Is he the one that’s driving? No, his friend’s driving; he</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>might just be in the back seat. Oh yeah. No, wait</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Michael</td>
<td>Assume he’s in the front seat too, that’s a good point because he</td>
<td>1</td>
<td>CD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>would hit the seat and that would disrupt our calculations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Isaac</td>
<td>no, you could still hit your seatbelt before hitting the seat.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Kirk</td>
<td>you could still hit the … dashboard</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Michael</td>
<td>That’s true</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Kirk</td>
<td>just assume that</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Isaac</td>
<td>part of why we have seatbelts is so you don’t fly into the seat.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Kirk</td>
<td>Assume the seatbelt stops him before he hits something.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Michael</td>
<td>That would suck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Isaac</td>
<td>That would suck so hard.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>I mean you’re either sitting behind a seat and you fly into the seat,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>or you’re not sitting behind a seat and you fly out the window</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Kirk</td>
<td>I mean I would way rather fly into the seat than fly out of the</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>window.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Michael</td>
<td>Have you ever been hit in the face by an airbag?</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td>16</td>
<td>Kirk</td>
<td>I had a guy - a guy in my high school went through the windshield,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>and he had the most like serious type of concussion. He had,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>through his</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Isaac</td>
<td>Sometimes it’s actually better to be outside of the car than inside.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Michael</td>
<td>I took an airbag in the face when we were doing like 30, and it</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>sucked. It was like “doing”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Isaac</td>
<td>&quot;boom&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Michael</td>
<td>Yeah you wake up like 2 minutes later and it’s like, &quot;Um?&quot; And you're</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>bleeding all down your face and shit.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Isaac</td>
<td>And you got like burns on your faces too right?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Michael</td>
<td>It’s not very fun. We weren’t going very fast. If the airbags hadn’t</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>fired we wouldn’t have gotten hurt at all.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Isaac</td>
<td>(laugh)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 25: Transcript to illustrate Procedural Discussion, Conceptual Discussion, and Off-Topic epistemological frames.*
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>Michael</td>
<td>Because the airbags fired, both of us were bleeding out of our noses and all</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Kirk</td>
<td>They get - they fire out at like insane speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Isaac</td>
<td>They, they are fast.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Michael</td>
<td>60km or something. It’s nasty, it’s like getting hit in the face with a brick wall. It sucked.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Kirk</td>
<td>We assume the mass is 100k, we assume he’s wearing a seatbelt.</td>
<td>PD</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Michael</td>
<td>This is for the first situation right? Or this is for both situations?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Isaac</td>
<td>Yeah they work for both.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Kirk</td>
<td>There's no airbag, the seatbelt stops him before he hits something.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Michael</td>
<td>Ok, perfect. What other assumptions have we got?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Kirk</td>
<td>Anything else?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Isaac</td>
<td>He is a man. We’ve been assuming that the entire time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Gordon</td>
<td>(laugh) well</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Michael</td>
<td>Car stops in either</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Kirk</td>
<td>Well we’re all guys</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Michael</td>
<td>I don’t know if those are assumptions. The car stops in either 1 or 20 meters. Is that an assumption? It’s kind of given to us isn’t it?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Gordon</td>
<td>yeah I think it’s given</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Isaac</td>
<td>It’s one of the like basics for solving the question</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Michael</td>
<td>It just says that 20 meters per hour is the stopping distance, so let’s just assume that the manual is correct for the car and that it actually stops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>Isaac</td>
<td>Assume that the stopping distance is actually 20 meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Michael</td>
<td>Yeah I think that’s important</td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>Isaac</td>
<td>Also assume that an emergency stop would be exactly at 1 meter.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Michael</td>
<td>That’s good, and I think we’re pretty good.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>Kirk</td>
<td>We gotta draw the model and then we gotta solve.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>Isaac</td>
<td>Draw some pretty pictures, draw some free form diagrams.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 25: Transcript to illustrate Procedural Discussion, Conceptual Discussion, and Off-Topic epistemological frames
The above transcript includes four segments: students working in a Worksheet frame, a Conceptual Discussion frame, an Off Topic frame, and a Procedural Discussion frame. Throughout this transcript the students are engaged in discussion with each other, but the implicit goal of their conversation shifts a couple of times.

The transcript begins with the interrogative “what else?” and the subsequent few lines are conducted in a clipped, matter-of-fact tone of voice. This question and the tone of the exchange imply the students are framing their current activity as filling out a list of requirements. This activity of filling out requirements is a common activity during these recitations, and is characteristic of the Worksheet frame. When the students are framing their activity in this way their discussion revolves around interpreting the requirements and searching for the right answers that will satisfy the requirements. As is evident in lines 1 and 2, there is little discussion of the merits of listed items.

The implicit goal of this conversation begins the change in line 4. Michael proposes another assumption to be added to the former list but then expands this assumption by interpreting its consequences for the calculation: “that’s a good point because he would hit the seat and that would disrupt our calculations.” This suggests consideration of the implications of the assumptions in terms of the actual narrative of the situation. Isaac responds on line 5 by making a qualitative argument about the sequence of events in the crash. The subsequent discussion between Kirk, Michael, and Isaac makes it clear that the focus of discussion has shifted from listing assumptions to conceptually exploring the interactions of a seatbelt and a seat during a car crash.

These discussions inform the students' assumptions in the problem and their subsequent calculations. This example of reasoning from conceptual or narrative representations of a problem to make claims in mathematical or logical representations is a key characteristic of the Conceptual Discussion frame. Instead of speaking strictly in terms of the elements and rules of formal
mathematical reasoning, the students are coordinating their understanding of the story of the problem with the mathematics.

At line 15 the discussion of car crashes prompts Kirk to relate a personal anecdote about a car crash. While there is physics knowledge brought up during the discussion, it is clearly not focused on the understanding specific content of the problem or making progress towards the solution, and as such it is coded as Off Topic.

The students resume their focus on filling in the assumptions list on line 28, where Kirk recounts their earlier assumptions. Michael immediately responds with a question relevant to the problem, indicating that he has abandoned the previous line of (off-topic) conversation and is now re-engaged in solving the problem. The subsequent discussion shows that the students have returned to considering what other assumptions, if any, are necessary in order to meet the standards of this particular step. During this step of the transcript there is rapid, responsive commentary on each other’s ideas. Hence, despite the focus on completing worksheet requirements, this segment is coded as Procedural Discussion.

On line 38 Michael raises the concern that he doesn’t “know if these are assumptions.” This is a telling comment; he almost certainly knows a definition of the word “assumption,” but in this context he is concerned about meeting the formal definition of “assumption” that is required for this step of the worksheet. This concern for meeting the perceived standards of the marker or the worksheet is characteristic of the Procedural Discussion frame.

Finally, on lines 46 and 47 students explicitly discuss their next steps. This strategic discussion matches the goal of “figuring out what to do” quite closely, and is also coded as Procedural Discussion.

6.3.4.8 Framing Inter-Rater Reliability Testing

To verify the reliability of using this frame coding scheme, an Inter-Rater Reliability (IRR) study was conducted. Two researchers independently coded
the same transcripts, coding each segment of the transcript as one of the frames in this scheme. The inter-rater reliability was calculated based on the percentage of frames that both raters coded similarly.

One of the key assumptions in our coding methodology is that each member of the group is in the same frame at the same time. However, examination of the dynamic of the bid and take-up of frames shows that frame transitions take some time and during frame transitions not all of the group members are in the same frame. When coding from audio-only data we must often wait for one of the group members to provide an explicit, verbal take-up of a new frame before we have clear evidence that the group has indeed changed frames. As such, it is hard to be sure of whether a frame change has occurred until at least two verbal statements have been made in the new frame: a bid to enter a new frame and a response indicating take-up of the frame. By contrast, one can make inferences about a group’s take-up of a new frame from video data by examining the group members’ body language, which provides much clearer and quicker feedback. This means that our coding scheme has an inherent uncertainty in the timing of a frame change of approximately two statements.

This uncertainty in the location of the frame change is a significant challenge for attaining high inter-rater reliability of coding. While we attempt to code the beginning of a clear and unambiguous new frame right when it begins, for a more ambiguous bid we often code in the first location where we have clear evidence that a second student has taken up the new frame. This difference in when a new frame may be coded leads to many situations in which two coders will choose a different beginning point for new frames.

Rather than treat these small differences as significant, I instead admit the fact that frame changes are an interactional phenomena, and as such do not occur in an instant. Rather they are the result of communication between group members and the process of proposing a new frame and agreeing to it take time. Therefore, I have chosen to code the inter-rater reliability of frame
changes to within 6 seconds. Because the average length of a single statement in the transcript is approximately 3 seconds, a 6 second window of uncertainty on the frame changes corresponds to ± 2 statements which seems appropriate for the interactional nature of this phenomena.

With this in mind, the inter-rater reliability is calculated as follows:

1. Each rater codes independently, identifying frame shifts and assigning each statement in the transcript to one of the frames.

2. For each frame transition, if the other coder marked a similar frame transition within 6 seconds, these transitions are considered to be the same and there is no accumulated error.

3. If both coders mark the same frame transition with more than a 6 second difference between the times, the entire difference in time is counted towards the accumulated error.

4. If one coder marks a transition into a new frame and the other coder does not, the entire length of the new frame is counted towards the accumulated error.

5. The inter-rater reliability is calculated as: \( IRR = 1 - \frac{(\text{accumulated error})}{(\text{total length of time coded})} \)

After coding and comparing a segment, I would discuss with the other coder about our disagreements and make refinements to the coding scheme. This process of coding, comparison, and discussion was repeated until we were able to code 80% or better Inter-Rater Reliability prior to discussion for three consecutive coding sessions without making any further refinements to the tutorial coding scheme, thus demonstrating that the final scheme could be coded consistently.

During the process of refining the coding rubric and establishing good IRR we coded five context-rich problems. The time coded, error rates, and IRR are reported on Table 26 below. The average IRR for coding of these problems was
84%. All of the disagreements in coding were discussed and we were able to reach a consensus in every case.

<table>
<thead>
<tr>
<th>Episode #</th>
<th>Total Time Coded (sec)</th>
<th>Total Errors (sec)</th>
<th>Total Errors ±6 sec (sec)</th>
<th>IRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2096</td>
<td>465</td>
<td>441</td>
<td>79%</td>
</tr>
<tr>
<td>2</td>
<td>1201</td>
<td>197</td>
<td>189</td>
<td>84%</td>
</tr>
<tr>
<td>3</td>
<td>2402</td>
<td>496</td>
<td>486</td>
<td>80%</td>
</tr>
<tr>
<td>4</td>
<td>1193</td>
<td>139</td>
<td>139</td>
<td>88%</td>
</tr>
<tr>
<td>5</td>
<td>1800</td>
<td>138</td>
<td>138</td>
<td>92%</td>
</tr>
<tr>
<td>Total</td>
<td>8692</td>
<td>1451</td>
<td>1393</td>
<td>84%</td>
</tr>
</tbody>
</table>

Table 26: Inter-rater reliability testing for epistemological framing coding scheme. The IRR is calculated as 1 - (total of errors that are greater than 6 seconds) / (total time coded)

Because of the importance of the Conceptual Discussion codes in our analysis, a separate IRR calculation was conducted for only those codes. Using the same 6 second margin of error, the average IRR for Conceptual Discussion for the same five problems listed above was 80%.

After establishing this reliability, I used the finished coding scheme to code all of the audio data in the study.

6.3.4.9 Limitations of Coding Methodology

After developing this framing coding scheme and using it to code this data set, it is clear that there are several weaknesses of this methodology. One weakness is that decisions about students framing need to be made purely on the basis of audio data. These have been discussed above in the section on comparing audio and video coding and it seems from the studies that we have conducted that this is not a major weakness. The lack of video data requires us to make guesses about students’ attention based on patterns of conversation but without specific information about how students are orienting their body and gaze. These guesses appear to be mostly correct, but likely rest on shared cultural experience and so may not be generalizable to the circumstance of a
researcher making judgments about a context with which they are not intimately familiar.

The reliance upon audio data for determining group framing is less of a problem when the group is interacting with each other frequently. It is much easier to infer students' attention to each other (or not) when there is speech data available from many members of the group. However, it is much more difficult to determine where the group's attention is when one student speaks for an extended period. My work with video showed that in some cases one student might be speaking very clearly while the other members of the group are focused on their papers. Their silence suggests that they are listening and or paying attention, but video reveals that this is not always the case.

In this coding scheme, we use a rule of thumb that if a student makes an extended statement (“extended” here being taken to mean more than a few seconds) that silence on the part of your students is taken to indicate attention and implicit assent. While our comparison with the audio-only coding study indicates that this is true most of the time, we know that some of the time students are not paying such close attention to each other.

Another issue is that in some groups the dialogue is dominated by one student. In one episode, one student spent the entire session thinking out loud, giving directions to other students, and asking questions which she would then subsequently answer for herself. Her group mates expressed their support for her decisions and framing very quietly and passively. In order to successfully code the group's attention during this segment, it was necessary to listen to quite a bit of the audio, make a judgment about the normal patterns of conversational turns and dynamics for this group in particular, and then make use of that model of group dynamics to infer the students' attention and subscription to epistemological frames.

This raises the other principal weakness of this methodology: the assumption that the entire group is attending to the same thing and framing their
engagement in the same way. Again, for a well-functioning group that is collaborating this assumption is likely valid. However there were many instances, even in otherwise well-functioning groups, where there was evidence that one or more members of the group had split off and were engaged in a different activity. Indeed, some groups spent much of their time operating in this split fashion. This splitting of the group’s attention is likely enabled and encouraged by the fact that in Physics 100 we only give each group a single recitation worksheet to work on. Many of these split attention episodes occur when one or more students are focusing on conducting calculations and/or recording the group’s work. The other students, perhaps feeling that their input is not needed in this moment, will often move on to the next part of the problem or converse about something unrelated.

Because this attention splitting behavior was reasonably common, it was necessary to account for it in the coding scheme. Whenever there is clear evidence that different students in the group are attending to different tasks and different frames, a “split frame” is coded. Because of the aforementioned difficulty in evaluating the attention of group members who are silent, this type of split frame is only coded when there is clear audio evidence of two different frames, such as when there are two competing conversations occurring or when one can clearly hear the sound of a student calculating under their breath as they write while the remainder of the group is engaged in conversation.

A protracted split in epistemological framing within a group is not mentioned in the Scherr and Hammer study. However I believe this is a consequence of the cohort chosen for their study. Scherr and Hammer's original result was based on video that had been preselected for the most “watchable” groups: groups who displayed a tendency to work together and speak to each other frequently. Groups that displayed a tendency to work independently or were uncooperative with each other were explicitly excluded from their analysis. Because my analysis attempts to span a wider, more representative set
of students it is not surprising that I should encounter some groups that are communicating and collaborating with each other at less-than-peak capacity.

One final issue with coding from audio only is that, despite using stereo recording equipment, it is not always easy to tell exactly which student is speaking. Largely, this is not a major problem because our framing coding looks at the group as the unit of analysis so it is not as important to determine precisely which student is speaking. However, because it is occasionally necessary to determine who is speaking for the purposes of evaluating the overall group dynamics or identifying a split frame, this difficulty in determining who is speaking can complicate the coding process.

Despite the above-mentioned weaknesses in using audio for coding epistemological framing, we believe that the audio/video comparison study and our own inter-rater reliability study demonstrates that this coding scheme is both reliable and gives substantially the same results as coding using full video.

6.3.5 Coding Real-World Connections

A crucial piece of my analysis of students' real-world connections in recitations is operationalizing when students were making a real-world connection. In order to develop a scheme for coding real-world connections I needed to more clearly define what a "real-world connection" means.

One interpretation of the idea of a "real-world connection" in science class is that it is simply a moment where a student makes use of their intuitive understanding of the real world in a science context. The Physics 100 recitations were explicitly designed to encourage and require this type of connection, with multiple instances where the details of a problem were vague or absent, requiring students to make assumptions and flesh out the situation in a sensible way.

I argue that another kind of meaningful real-world connection occurs when a student pictures the immediate scientific idea under discussion as being a part of their real-life or illustrates scientific ideas according to their own expectations of a realistic situation. By working to construct narratives of physics problems that are mutually
plausible to both the scientific and the everyday, the students create opportunities for themselves to see science as more connected to the real world. I do not argue that these events necessarily change students' perception of the relevance of science to the real world, only that they have the potential to do so.

To summarize, we operationalize a Real-World Connection as any opportunity for students to integrate their everyday and formal reasoning skills OR to affect their perception of the relevance of physics to the real world. These moments are characterized by simultaneous activation of physics resources and everyday resources. (e.g. knowledge, strategies, contextual frames)

In the following sections, I will describe the coding scheme used for identifying these two general categories of students’ Real-World Connections in a recitation context. I will first discuss the goals of the coding scheme. Then I will describe the development of the scheme and concurrent Inter-Rater Reliability study. Finally, I will give the details of the coding scheme and illustrate with example transcripts from student dialogue.

**6.3.5.1 Development of RWC Coding Scheme**

To develop this coding scheme, I first started by reviewing student audio and transcripts with the rough definition above in mind and identifying instances where I felt that the students were making meaningful real-world connections. After development of an initial scheme I began working with another physics education researcher in order to refine the scheme to incorporate new perspectives on real-world connections that emerged from the data and such that it was internally consistent and capable of high inter-rater reliability.

As soon as we started formal coding we saw immediately that real-world connections tended to occur in clusters, informing and reinforcing each other as students discussed or debated a particular point.

The coding scheme underwent considerable revision, but reaching our goal of 80% inter-rater reliability proved to be difficult. Initially, we were evaluating
inter-rater reliability on a statement-by-statement basis. This led to the difficult and frustrating results where the two researchers would both code a cluster of real-world connections, but would code the individual statements within that cluster differently. At that time we were trying to only code “new” connections, and avoid coding anything that was a repeat of an earlier statement or idea. This meant that in circumstances where students built upon each others’ ideas, a difference in our judgment regarding which idea was the first would yield no agreement in our codes, even though both researchers had clearly identified that there were real-world connections emerging in the students’ interactions.

The above problems were relieved when we shifted our perspective on what constituted a meaningful real-world connection. We realized that the reason that real-world connections tended to occur in clusters was that students engaged in collaborative group problem-solving were co-creating these connections and while an individual statement by an individual student might not encapsulate an entire idea, it could contribute to the ongoing evolving idea that was being developed by the group.

With this new perspective of recognizing the importance of the students’ interaction with each other and the distributed nature of the real-world connections, we also started to see the importance of repetitions. When a student repeated a real-world connection that had been made by one of their peers they were often questioning it or reinforcing it, actions that had important meaning for the ongoing negotiation of that idea. Similarly, when a student repeated a real-world connection that they themselves had recently made, it often functioned as an emphasis to support their argument for that idea.

Therefore, we agreed to change the scheme in 2 ways:

1. In recognizing the co-created and distributed nature of real-world connections, we would code with the individual statements as the unit of analysis but with a ± 6 second margin of error. This means that if one coder had coded a real-world connection, that code would be considered “good” if the
other coder had similarly coded a real-world connection within 6 seconds. Because the average length of a statement in the data set is approximately 3 seconds, this corresponds to a ±2 statement margin of error.

2. Recognizing the important social and argumentative value of repetitions in the context of an evolving group discussion, we code students’ repetitions of their own ideas or of others’ ideas when those repetitions were made in service of developing an ongoing argument or idea. Repetitions of earlier real-world connections that were merely reciting what had been decided earlier without challenging or adding anything to it would not be coded.

6.3.5.2 RWC Inter-Rater Reliability Testing

The following table shows the Inter-Rater Reliability of all of the episodes coded during the coding scheme development. Midway through the scheme development, it was necessary to switch to a different coding partner due to the beginning of a new term and Coder #1’s concomitant teaching responsibilities. Work with the next coder shows a steady increase in IRR until we reach a consistent performance of better than 80% IRR without significant changes to the coding scheme. As with the development of the epistemological framing coding scheme, I judged this consistent performance of better than 80% IRR as evidence of sufficient reliability.
Table 27: Inter-rater reliability testing for Real-World Connections coding scheme. The IRR was calculated as 1 - (number of RWC coded more than 6 seconds from the other coders’ RWC) / (total number of RWC coded).

6.3.5.3 Summary of RWC Coding Scheme

As described above, the following categories of real-world connection emerged from our desire to find an internally consistent coding scheme that identified instances where students were synthesizing physics knowledge and real-world knowledge, or were making use of real-world knowledge in a meaningful way in their problem-solving.

Although we came to recognize the interactional and distributed nature of these real-world connections, for the purposes of coding the unit of analysis was taken as a single statement.

Firstly, because we are implicitly treating the real-world connections as positive uses of everyday resources in a physics context, any comments that are explicitly negative about the realism of the recitation problem were considered to be Negative RWC. For example, when a student says “If we'd do this in real life, I think we'd just use common sense [instead of physics],” they are implying that physics is not useful in real life. While the students are making a
connection between physics and the real world, this connection seems unlikely to contribute to a positive opinion of the relevance of physics to the real world and is therefore considered separately (see section 6.4.5 below).

Note that categorization as negative RWC was reserved for comments that were explicitly negative. Many comments could have been interpreted as revealing students’ negative judgment of the realism of the tutorial, but this analysis would require in-depth analysis of the function of those comments within the broader conversational context which is a level of analysis to which this coding does not extend. Rather, in order to maintain a fairly simple coding scheme that enabled high IRR and in order to assess a larger corpus of data, I chose to make this judgment of Negative RWC only on those statements where the students made their judgments explicitly.

After identifying the explicitly negative RWC, five major categories of real-world connection were identified, listed in Table 28 below. Each category is listed with an Archetype statement, which is an idealized example of the kind of statement that would be given that particular code. These categories are described in more detail in the following sections, and the full coding rubric is available in Appendix E.
<table>
<thead>
<tr>
<th>RWC Category</th>
<th>Definition</th>
<th>Archetype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumption</td>
<td>Use of RW resources to define mathematical relationships</td>
<td>“Because of X in the real world, we should use value Y in our calculation”</td>
</tr>
<tr>
<td>Interpretation</td>
<td>Use of RW resources to interpret meaning of abstract forms</td>
<td>“These abstract or mathematical forms must mean X” (because of my knowledge of similar situations)</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Use of RW resources to evaluate plausibility of results</td>
<td>“Our answer can’t be right because that would have unreasonable consequences”</td>
</tr>
<tr>
<td>Personalization</td>
<td>Use of RW resources to illustrate situation described in tutorial</td>
<td>“If I were in this situation, this is what I would do.”</td>
</tr>
<tr>
<td>Meta-statement</td>
<td>Use of RW resources to comment on realism of recitation problem itself</td>
<td>“I doubt that anyone would ever do this.”</td>
</tr>
</tbody>
</table>

Table 28: Types of real-world connection identified during collaborative group problem-solving in introductory physics.

Early in the development of the coding scheme, the two researchers would code each instance of real-world connection by what type it was in the taxonomy. We discovered that it was very common for us to disagree on the type of real-world connection, even when we had very high agreement on which statements were real-world connections. This is a clear indication that the following taxonomy does not represent non-overlapping categories. However, this list is still valuable in that two researchers working from this taxonomy can achieve high inter-rater reliability in identification of statements that meet one or more of these categories.

**Assumption**

The first category of real-world connections is Assumptions. This refers to instances where students use their knowledge of everyday relationships and quantities in order to define quantities or mathematical relationships within their model. The context-rich problems used in Physics 100 are designed to require students to make some assumptions in order to solve them. These assumptions can be anything from students assuming the speed of a car is 50
km/h to assuming that the airbags don't deploy during a crash, which would affect the force exerted on a passenger by their seatbelt.

Because not all assumptions that students make are rooted in their knowledge of the real world, assumptions which are not explicitly connected to a real world situation and are mathematically convenient are not coded. An example of this type of bald assumption would be if the students assume that the emissivity of an object is 1 with no further explanation. The assumption is made without reference to any feature of the situation under consideration and it is clearly the best choice for simplifying the calculations. However, if the students say “this object is basically black, so we can use an emissivity of 1” they have grounded their assumption in a meaningful characteristic of the object under consideration.

**INTERPRETATION**

The second category of real-world connections is Interpretations. This category includes interpretations of mathematics or abstract forms in terms of more everyday language or explanations. Instances where students interpret the narrative of the problem situation in terms of their own knowledge of similar situations also fall into this category. Students may make interpretations of the recitation problem itself or a formula that they have looked up or constructed.

In the following example the students are trying to interpret a formula for conductive heat loss that has a term of the form $2^*(l*w + w*h + l*h)$. 
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Colin</td>
<td>(interrupting) this is dimensions</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Earl</td>
<td>this is different</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Colin</td>
<td>this is length, width, depth, so that's A. So it's saying that something with.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(...)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Alex</td>
<td>wait how is that area? how is that area?</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Colin</td>
<td>it's just dimensions of something right?</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Alex</td>
<td>yeah, but it wouldn't be area cuz they're added together.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Earl</td>
<td>yeah they're added not multiplied.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Colin</td>
<td>oh that's true. but they're also multiplied, so it could be the left wall plus the right wall</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Alex</td>
<td>yeah that could be area of, like walls or something</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 29: Example of Real-World Connection as Interpretation.

This example illustrates how a real-world interpretation can build over the course of several statements. Colin begins by interpreting that the term is “dimensions”, and then after some discussion proposes that these variables could correspond to “walls”. The interpretation that the area corresponds to walls was not directly encoded in the algebra provided, but is instead the result of the students’ interpretation of the math in terms of what they already know. In this transcript, lines 11 and 12 would be coded as RWC.

**Evaluation**

The third category of real-world connection is Evaluation. This category indicates when students make a judgment about a result based on explicit discussion of a realistic situation or by merely using their intuition. This type of evaluation may rest on intuitive reasoning resources such as those described by diSessa [30]. A simple “wow, that's a big” indicates that the student has compared the quantity under consideration to their intuitive knowledge about the world. Alternatively, an Evaluation may take the form of a reasoned argument and estimate about the magnitude of realistic quantities in the world.
In the following transcript the students have just gotten an answer of 12 m/s from a calculation to find the speed of a car.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gaston</td>
<td>oh. 12 m/s is actually like 40 k, 40 k an hour.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Karl</td>
<td>well, calculate it!</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Gaston</td>
<td>40 something k an hour. 40 something kilometers an hour. Because Olympic sprinters, right? They take 10 seconds to sprint 100 meters and that's about 40 km/h, right?</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Imogen</td>
<td>divide by...</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Gaston</td>
<td>yes they sp... they run really really fast. really really fast</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Imogen</td>
<td>43!</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Gaston</td>
<td>twice as fast as the average sprinter actually. 43 yeah, that seems reasonable</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 30: Example of Real-World Connection as Evaluation.

In this example, Gaston evaluates the reasonableness of the result of 12 meters per second by using his knowledge about Olympic sprinting. His final statement the car is “twice as fast as the average sprinter” shows clearly how he is using this everyday knowledge to make sense of the result.

**PERSONALIZATION**

All three of the above categories are directly related to making progress in the problem solution. The next two categories do not directly contribute to problem solving, but instead identify situations where the students’ perception of the relevance of the problem to the real world may be affected.

The fourth category of real-world connection is Personalization. This occurs when the students describe themselves as being in the problem situation. They may do so in a joking fashion, or may quite seriously discuss what that situation might be like or flesh it out with details drawn from their own experience. Note that simply telling stories about their real world experiences is not coded in this category. Rather, this category includes circumstances where students are
connecting their experiences to the situation described in the recitation problem.

In the following example, the students have just completed a calculation to determine how much money they would save in driving to California at 90 km/h instead of 100 km/h. Upon discovering that their result is $7, they briefly discuss what would come of that $7 if they were actually traveling to California.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sally</td>
<td>We can all buy a cookie from. with.</td>
</tr>
<tr>
<td>2</td>
<td>Frederick</td>
<td>two cookies</td>
</tr>
<tr>
<td>3</td>
<td>Sarah</td>
<td>(laughs) a seven dollar cookie</td>
</tr>
<tr>
<td>4</td>
<td>Sally</td>
<td>we can ALL buy one. There's three of us. (laughs) Frederick...</td>
</tr>
<tr>
<td>5</td>
<td>Sarah</td>
<td>(laughs) Frederick's not...</td>
</tr>
<tr>
<td>6</td>
<td>Jennifer</td>
<td>poor Frederick.</td>
</tr>
</tbody>
</table>

*Table 3.1: Example of Real-World Connection as Personalization.*

The students, speaking as though they are actually in the problem situation, discuss what they would do with the $7. Because the problem specifies that only three students are in the car, they had previously decided to exclude Frederick, the only male student in the group. In lines 4 through 6, the students jokingly console Daniel as though he had actually been left behind.

By engaging in this type of imaginative putting-oneself-in-the-scene the students are implicitly treating the problem situation as realistic and potentially applicable to themselves. This constitutes an important opportunity for their views regarding the relevance of physics to their everyday lives to change.

*Meta-Statement*

The last category of real-world connections is meta-statements. This category occurs when students make direct comments about the realism (or unreality) of the tutorial itself. With these statements, the students reveal their
opinions of the relevance of the problems that we have set to themselves and their lives, and as such I believe this is a very important category to consider. These statements are usually explicitly negative, and are therefore coded as Negative RWC.

The following transcript gives an example of a meta-statement. The students are discussing a problem where they are told that they will be tying a fridge near the back of a pickup truck’s bed by means of two lengths of rope. They have been instructed to determine if the rope will hold in the event of an emergency stop or a crash. (See page 316 in Appendix A for the full problem)

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rafael</td>
<td>so we tie the rope in two places.</td>
</tr>
<tr>
<td>2</td>
<td>Tony</td>
<td>in two places, cause he doesn't have enough rope, cause he's cheap.</td>
</tr>
<tr>
<td>3</td>
<td>Rafael</td>
<td>what does that mean, tie the rope in two places?</td>
</tr>
<tr>
<td>4</td>
<td>Tony</td>
<td>It means that Physicists don't have enough rope.</td>
</tr>
<tr>
<td>5</td>
<td>Rafael</td>
<td>so if he had enough rope, he would tie it in more than two places</td>
</tr>
<tr>
<td>6</td>
<td>Tony</td>
<td>In 18 million places like everyone else who owns a pickup, and not screw up, and not have a collision, and not, you know, have a few beers while moving, and then drive.</td>
</tr>
</tbody>
</table>

Table 32: Example of Real-World Connection as Meta-Statement.

In line 2, Tony derisively notes that the character in the problem is “cheap.” The students continue to mock the lack of rope described in the problem, and finally Tony says that if the character had enough rope he would tie the fridge “in 18 million places like everyone else who owns a pickup.” His tone in this statement is one of mild frustration.

These comments reveal these students’ opinion of the realism of this problem. I believe that Tony is frustrated by what he perceives as an arbitrary limitation in this problem. In an actual real-world situation of tying down a fridge in a truck, he would tie the fridge down in many locations in order to be sure it is secure. The purported scarcity of rope in the problem is used as a motivation to conduct a calculation, but he quite sensibly objects to this
artificial limitation. His statements reveal that he perceives this problem to be unrealistic and irrelevant to real life, a perception which certainly has the opportunity to change his perception of physics as a whole. In this transcript, lines 2, 4, 5, and 6 are coded as Negative RWC.

6.3.6 Equivalence of Frames and Codes

One assumption of this analysis is that all Real-World Connections are equivalent and each minute spent in a particular frame is equivalent. Although some moments of conversation hold far greater importance for participants than others and some moments have far greater potential for learning, I do not attempt to identify which Real-World Connections or which instances of Conceptual Discussion have a greater or lesser impact on students’ learning or beliefs. I argue that on average, if student groups spend more time engaging in Conceptual Discussion then they will have more opportunities to make connections between different representations of their physics knowledge and to develop their conceptual understanding of the problems and procedures that they are working with.

6.4 Coding Results and Analysis

6.4.1 Selection of Data

Not all of the data is included in the analyses below. In one of the episodes there was a bonus question and so any work that a group did on the bonus question was excluded from the analysis because it falls outside the normal structured problem solving prompts. The excluded data represents 1.5% of the total time coded.

There were a few pieces scattered across the episodes where a clear frame could not be identified, which were also excluded from this analysis. These represent less than 0.5% of the total time coded, and there were no RWC coded during those pieces.

As mentioned in section 6.3.5.3 above, Negative Real-World Connections are considered separately from those that are not explicitly negative. A total of 405 RWC were coded across the 14 episodes. Of those, 14 were associated with the Bonus question, and 38 were Negative RWC, leaving 353 RWC in the main analysis.
6.4.2 Correlation Between Frame and RWC

In order to investigate the factors that influence whether and how students make RWC we start by examining the relationship between their framing and RWC. According to the theory of resources and framing, frames regulate a person's access to the various resources, and so we expect to see that students more readily access the real-world knowledge in some frames than others.

To examine how students’ frames correlate with their RWC, we look at the number of RWC that occur in each frame. However, the number of RWC alone is not adequate to determine whether a certain frame promotes or inhibits the generation of RWC. Because students spend different amounts of time in different frames, it would be reasonable to imagine that students might make more RWC in frames that they spend more time in. To compensate for this effect, we also look at the frequency per unit time of RWC that occur in each frame. These results are listed on Table 33 below and are discussed in the following sections.

<table>
<thead>
<tr>
<th>Frame</th>
<th>Total length of frames (min)</th>
<th>Percentage of total time (%)</th>
<th>Total # of RWC</th>
<th>Frequency of RWC (min^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedural Discussion</td>
<td>158.47</td>
<td>23%</td>
<td>101</td>
<td>0.64</td>
</tr>
<tr>
<td>Conceptual Discussion</td>
<td>51.20</td>
<td>7%</td>
<td>137</td>
<td>2.68</td>
</tr>
<tr>
<td>Meta</td>
<td>3.78</td>
<td>1%</td>
<td>13</td>
<td>3.44</td>
</tr>
<tr>
<td>Off topic</td>
<td>73.70</td>
<td>11%</td>
<td>27</td>
<td>0.37</td>
</tr>
<tr>
<td>TA</td>
<td>84.43</td>
<td>12%</td>
<td>18</td>
<td>0.21</td>
</tr>
<tr>
<td>Worksheet</td>
<td>324.03</td>
<td>47%</td>
<td>57</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>695.62</strong></td>
<td><strong>100%</strong></td>
<td><strong>353</strong></td>
<td>...</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>...</td>
<td>...</td>
<td>...</td>
<td><strong>0.51</strong></td>
</tr>
</tbody>
</table>

Table 33: Summary of time spent, Real-World Connections, and frequency of real-world connections by epistemological frame.

6.4.2.1 Frequency of RWC by Frame

Table 34 shows us that students make most of their RWC in the Procedural Discussion and Conceptual Discussion Frames. While the number of RWC is similar between the Procedural Discussion and Conceptual Discussion frames,
students spend more than 3 times as much time in the Procedural Discussion frame on average. This results in a frequency of RWC in the Conceptual Discussion frame that is more than 4 times higher than in the Procedural Discussion frame.

To check for statistical differences in RWC frequency between frames we use a statistical Analysis of Variance (ANOVA). This is especially important because there is a large variation in frequency of RWC across the different episodes in the study. The variation in RWC frequency across the 14 episodes in the study is depicted in Figure 13 below.

---

**Figure 13:** Boxplot of frequency of RWC in different Frames across the data set (N=14 episodes). The dark bar shows the median, the box shows the 25th - 75th percentiles, and the whiskers show the range of the data. Outliers, more than 1.5 times the inter-quartile distance, are marked with circles. The Triangle symbols mark the average value for each episode.
Analysis of Variance of frequency of RWC between frames and pairwise Tukey Honest Squared Differences comparisons of the RWC frequency shows that the Frequency of RWC in the Conceptual Discussion and frame is higher than it is in the Worksheet, TA, Procedural Discussion, and Off-topic frames (p<0.01) and that the frequency of RWC in the Meta frame is higher than it is in the Worksheet frame (p<0.1).

This shows that Real-World Connections are strongly correlated with the Conceptual Discussion frame. This result supports our observation that the Conceptual Discussion frame is where we see students discussing and elaborating on each other's ideas. In these circumstances students are much more likely to repeat and elaborate each others’ ideas. Because RWC are coded at the statement level (i.e. each student’s turn at conversation may be coded as a RWC), back-and-forth conversation will result in a large number of RWC codes leading to a high frequency of real-world connections.

6.4.2.2 Investigation of Positive RWC in the M Frame

The Meta-comments frame, although it accounts for only 1% of the total time coded, contains 4% of the total RWC and therefore has very high frequency of RWC. This is surprising, considering that many of the RWC made in the Meta-comments are explicitly negative about the realism of the recitation problem and are therefore excluded from this analysis. (These comments are discussed in section 6.4.5 below)

The high number of positive RWC coded during a meta frames emerge from a particular snippet of conversation that occurs in episode 9. It is listed below.
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shary</td>
<td>There’s no way you- people stop going that fast in 20m. So it means you’re supposed to take 20m to stop?</td>
<td>-1</td>
<td>M</td>
</tr>
<tr>
<td>2</td>
<td>William</td>
<td>At 50km an hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Shary</td>
<td>That’s ridiculous! Isn’t that ridiculous? That seems way too long.</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>William</td>
<td>Too long?</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Virginie</td>
<td>20 meters?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Shary</td>
<td>Yeah. 20 meters isn’t that quite far?</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Virginie</td>
<td>Yeah it is</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>William</td>
<td>I’m really bad with distances so</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Virginie</td>
<td>Oh actually no. It’s not very far. It's not</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>William</td>
<td>Oh so that’s like an average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Virginie</td>
<td>Cause I run 30 meters at track practice and it’s not far.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Shary</td>
<td>Oh ok</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Virginie</td>
<td>20 meters-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>William</td>
<td>20 meters is like 60 feet, it’s kind of like just a little bit longer than this room.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Frances</td>
<td>Like you mean this way?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>William</td>
<td>Yeah</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Virginie</td>
<td>Really?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Frances</td>
<td>That’s all?!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Virginie</td>
<td>When I run it feels like it’s nothing but maybe.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>William</td>
<td>Yeah</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Shary</td>
<td>Ok well nonetheless it's not too long then</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 34: Transcript of RWC cluster in the Meta frame. These students have just read a recitation problem that states the stopping distance for a car traveling 50 km/h is 20 meters and are commenting on the realism of the problem itself during this segment. The “−1” in the RWC column indicates that statement was coded as a negative RWC due to being explicitly negative about the realism of the problem. A “1” indicates a RWC that is not explicitly negative about the realism of the problem.
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>William</td>
<td>Well ceiling tiles are a foot, right? So it’s easily 60 that way right?</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Frances</td>
<td>Yeah but actually, the length of this room is not that long, comparable to how big a car is</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Shary</td>
<td>But I thought it was too long so apparently I’m way off</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>William</td>
<td>Yeah</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Shary</td>
<td>It’s hard to say if it’s safe or not though because you can’t predict the future. You can’t predict what’s going to happen (laugh), how do you like-</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Virginie</td>
<td>Like if there was an accident or not right?</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>William</td>
<td>Exactly. If you’re in an accident yeah it’s probably not safe but. (laugh)</td>
<td>-1</td>
<td></td>
</tr>
</tbody>
</table>

Table 35: Transcript of RWC cluster in the Meta frame. These students have just read a recitation problem that states the stopping distance for a car traveling 50 km/h is 20 meters and are commenting on the realism of the problem itself during this segment. The “−1” in the RWC column indicates that statement was coded as a negative RWC due to being explicitly negative about the realism of the problem. A “1” indicates a RWC that is not explicitly negative about the realism of the problem.

This episode occurs during recitation 8, which asks to consider whether you have enough rope to secure a fridge in the back of a truck, and directs the students to consider two cases: the case of emergency braking where the stopping distance could be 20 m, and the case of a crash where the stopping distance could be 1 m.

The episode begins with Shary calling into question the realism of the problem’s statement that a car would stop in 20 m. This statement is coded as RWC because of the implicit use of her knowledge about the real world in making such a judgment. The next RWC statement also implies that the values supplied in the problem are unrealistic (or “ridiculous”), so these RWC are coded as negative and are therefore not counted in this analysis. (See section 6.4.5 for the discussion of negative RWC.)
The conversation then turns away from the realism of the problem to examine whether 20 meters should be considered “long” or not. At this point the students are still discussing things in terms of their knowledge and judgments about what is realistic, but they are no longer directly implying that the problem is unrealistic. These statements are therefore coded as positive RWC. The students’ subsequent discussion about distances generates many positive RWC, all of which are still in the Meta frame.

Near the end of the snippet they express another judgment of the realism of the problem; namely that it is ridiculous to ask whether it is “safe” to be in an accident. Because of the implication that the problem task is unreasonable these statements are coded as negative RWC.

While this snippet does illustrate some clear examples of RWC, it would be unwise to conclude that the meta-comment frame generally produces positive RWC for two reasons. The high frequency of RWC only occurs for a single group, and this high number of positive RWC in the Meta frame is the exception to the general pattern that students express negative opinions of the realism of the problem during the Meta frame. Therefore I do not expect that the high number of positive RWC occurring in the Meta frame is generalizable to other groups.

6.4.2.3 Examination of RWC by Episode

Figure 11 above shows a large variation in the RWC frequency, which suggests there might be some important differences between student groups that affect the number of RWC coded for them. To investigate this variation, we can start by looking at the total number of RWC for each group. Table 35 below breaks down the overall number of RWC for each group by frame, ordered by the total number of RWC made by each group.
Table 35: RWC by frame for each episode. The High group is episodes that have 32 or more RWC. The Low group is groups that have 18 or fewer RWC.

A striking feature of Table 35 is the high variation in the number of RWC. To depict the distribution of the number of RWC made by different groups, Figure 14 below shows a histogram of the number of RWC coded for each group.
Figure 14: Histogram of number of RWC by episode. The episodes are split into two categories: The High RWC groups have 32 or more RWC (N=6). The Low RWC groups have 18 or fewer RWC (N=8).

Figure 12 makes it clear that some episodes have a high number of RWC, some have a low number of RWC, but there are no episodes with 21-30 RWC.

The high variation in the number of RWC between different groups raises the question of why some groups make so many more RWC than others. In order to investigate this I divide these groups up into the High RWC groups and the Low RWC groups and then subsequently examine the differences between these groups on a number of other measures. The gap in the total number of RWC between 21-30 RWC seems like a natural breaking point, so I defined the Low RWC groups to be all the group with 18 or fewer RWC (N=8), and the High RWC groups to be all groups with 32 or more RWC (N=6). This split also has the advantage that there are nearly equal numbers of groups in each category.

**6.4.2.4 Do the High RWC Groups Engage in More Conceptual Discussion?**

We might hypothesize that the High RWC groups are more conceptually oriented than the Low RWC groups in general. If this were the case, we would expect that the High group might spend more time in the Conceptual
Discussion frame. Figure 15 below shows the amount of time each group spends in each frame during their recitation.

![Time Spent in Frames by HI / LO RWC group](image)

**Figure 15:** Time spent in each frame by High / Low RWC category. The High RWC groups have 32 or more RWC (N=6). The Low RWC groups have 18 or fewer RWC (N=8).

While on average the High group spends twice as much time in Conceptual Discussion and more time in Procedural Discussion, these are not statistically significant differences between groups.

Comparing the rate of Conceptual Discussion for the High RWC groups with the rate of RWC for those groups leads to an interesting conundrum. These groups make significantly more Real-World Connections than the Low RWC groups, but they do not spend significantly more time in the Conceptual Discussion frame than the Low RWC groups in any of the problem-solving steps. However, it is certainly true that the High groups in this study spent
twice as much time in CD than the Low groups in this study. Given that we know that RWC are correlated with CD, this would lead us to expect the High groups to have twice as many RWC as the Low groups. However they have much more than that, which suggests there is something other than scaling going on.

It turns out that when the High RWC groups engage in Conceptual Discussion they make more use of their own real-world knowledge than their peers in the Low group. This higher rate of RWC during the Conceptual Discussion frame accounts for most of the observed differences between the High RWC and the Low RWC groups.

### 6.4.2.5 Examination of RWC Frequency

A look at the frequency of RWC in each frame supports the statement made above that the High RWC groups make more use of their real-world knowledge during the Conceptual Discussion frame. Figure 16 below shows the frequency of RWC in each frame broken down by High and Low RWC.
Figure 16: Frequency of RWC in each frame by High / Low RWC category. The High RWC groups have 32 or more RWC (N=6). The Low RWC groups have 18 or fewer RWC (N=8).

Analysis of Variance for these RWC frequencies shows that the average frequency of RWC in the Conceptual Discussion frame for the High groups is significantly higher than it is for the Procedural Discussion, Worksheet, and TA frames for the High groups, as well as being higher than all of the RWC frequencies for the Low groups (p<0.05 for every pairwise comparison except for PD_HI > PD_LO, which has p<0.1).

There is no statistically significant variation between the various RWC frequencies for the Low groups. The Low groups do display a higher mean RWC frequency in the Conceptual Discussion and Meta frames, but the variability of RWC frequency in the Meta frame makes it impossible to be sure of a systematic variation. However, when the Meta frame is excluded from the
analysis, the Low group also demonstrates a higher rate of RWC in the CD frame than in all other frames (p<0.05).

This reinforces our earlier result that the Conceptual Discussion frame is correlated with increased frequency of RWC.

6.4.2.5 Real-World Connections in the Conceptual Discussion Frame

In order to better understand the correlation between RWC and the Conceptual Discussion frame I have looked more closely at the characteristics of RWC in the Conceptual Discussion frame. I have observed from the data that RWC in the Conceptual Discussion frame tend to be a part of back-and-forth conversations, and I have observed that students are more likely to express affective responses during these conversations. These observations are described in the following sections.

CLUSTERING

In reviewing the pattern of RWC in the transcripts we can see that the RWC in the Conceptual Discussion frame tend to occur in clusters. I examine the clustering patterns in the data by calculating a histogram of time between RWC in the different frames. This will give us a sense of what proportion of the RWC are occurring relatively soon after the previous RWC, and what proportion are occurring much later.
<table>
<thead>
<tr>
<th>Time between RWC (s)</th>
<th>PD</th>
<th>CD</th>
<th>M</th>
<th>O</th>
<th>TA</th>
<th>W</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>27%</td>
<td>19%</td>
<td>25%</td>
<td>48%</td>
<td>26%</td>
<td>13%</td>
<td>24%</td>
</tr>
<tr>
<td>4-6</td>
<td>6%</td>
<td>21%</td>
<td>25%</td>
<td>12%</td>
<td>11%</td>
<td>12%</td>
<td>14%</td>
</tr>
<tr>
<td>7-9</td>
<td>3%</td>
<td>11%</td>
<td>17%</td>
<td>15%</td>
<td>5%</td>
<td>4%</td>
<td>8%</td>
</tr>
<tr>
<td>10-12</td>
<td>7%</td>
<td>10%</td>
<td>8%</td>
<td>3%</td>
<td>11%</td>
<td>6%</td>
<td>8%</td>
</tr>
<tr>
<td>13-15</td>
<td>4%</td>
<td>6%</td>
<td>8%</td>
<td>6%</td>
<td>0%</td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td>16-18</td>
<td>4%</td>
<td>2%</td>
<td>0%</td>
<td>3%</td>
<td>0%</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>19-21</td>
<td>2%</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
<td>5%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>22-24</td>
<td>2%</td>
<td>2%</td>
<td>0%</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>25-27</td>
<td>1%</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>6%</td>
<td>2%</td>
</tr>
<tr>
<td>28-30</td>
<td>1%</td>
<td>1%</td>
<td>0%</td>
<td>3%</td>
<td>0%</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>&gt;31</td>
<td>42%</td>
<td>22%</td>
<td>17%</td>
<td>6%</td>
<td>42%</td>
<td>50%</td>
<td>31%</td>
</tr>
<tr>
<td>Grand Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 36: Percentage of RWC in a particular frame that are a certain # of seconds after the previous RWC. The bottom row indicates the percentage that are more than 30 seconds after the previous RWC.

Because the average length of a student statement is 3 seconds, looking at the top three rows of Table 36 will tell us how likely a RWC is to be followed up with another within the next three statements. We can see that in the Procedural Discussion frame, 27% of RWC are followed up by another within 3 seconds, but then after that the probability of another RWC drops off very rapidly and the total for the first 9 seconds is 36%. By contrast, in the Conceptual Discussion frame we are only 19% likely to see a follow-up RWC within 3 seconds but the total for the first 9 seconds is 51%.

Looking at the bottom row of Table 36 shows us what proportion of RWC occur more than 30 seconds after the previous RWC, indicating that they occur in relative isolation from previous topics of conversation. We can see that more than 40% of RWC in the Procedural Discussion frame occur in isolation whereas only 22% of RWC in the Conceptual Discussion frame occur in isolation. This pattern is borne out by direct reading of the transcripts, which
show that many RWC in the Worksheet and Procedural Discussion frames occur as a single observation that is discussed briefly, if at all.

Taken together, these patterns support a picture of RWC in the Conceptual Discussion frame as more likely to occur in protracted discussion. This type of discussion will involve many references to the same idea, all of which will be coded. An example of such a protracted discussion is given below. (Note that this is the same snippet used in section 6.3.4.6 above)
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Michael</td>
<td>it's not like he’s a slob</td>
<td></td>
<td>CD</td>
</tr>
<tr>
<td>2</td>
<td>Gordon</td>
<td>Gordon: k</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Isaac</td>
<td>Could be he’s a slob - who cares?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Kirk</td>
<td>assume he’s wearing a seatbelt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Isaac</td>
<td>Slobs don’t really</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Michael</td>
<td>yeah that’s a good assumption</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Isaac</td>
<td>Slobs don’t really break their ribs, so let’s assume this guy is heavy because he’s fit.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Michael</td>
<td>maybe he fell out of his bed</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Isaac</td>
<td>(laugh) If he was fat, he’d probably be cushioned.</td>
<td>1</td>
<td>O</td>
</tr>
<tr>
<td>10</td>
<td>Michael</td>
<td>Washing himself with a rag on a stick</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Isaac</td>
<td>(laugh)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Michael</td>
<td>Ok, what else? Well, we assumed that, um (pause) no airbag.</td>
<td>1</td>
<td>W</td>
</tr>
<tr>
<td>13</td>
<td>Gordon</td>
<td>All right</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Isaac</td>
<td>Isaac: Is he the one that’s driving? No, his friend’s driving; he might just be in the back seat. Oh yeah. No, wait</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Michael</td>
<td>Assume he’s in the front seat too, that’s a good point because he would hit the seat and that would disrupt our calculations.</td>
<td>1</td>
<td>CD</td>
</tr>
<tr>
<td>16</td>
<td>Isaac</td>
<td>no, you could still hit your seatbelt before hitting the seat.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Kirk</td>
<td>you could still hit the … dashboard</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Michael</td>
<td>That’s true</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Kirk</td>
<td>just assume that</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Isaac</td>
<td>part of why we have seatbelts is so you don’t fly into the seat.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Kirk</td>
<td>Assume the seatbelt stops him before he hits something.</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Table 37: Illustration of RWC clusters in the Conceptual Discussion frame.

In this snippet we can see the tight clustering of RWC made in the Conceptual Discussion frame. The students are negotiating their collective understanding of the importance of a particular assumption, which involves contributions from several group members. This type of clustered discussion is
responsible for the high RWC density in the Conceptual Discussion frame and the percentage of RWC that occur in isolation in the Conceptual Discussion frame.

**EMOTIONAL ENGAGEMENT**

Another interesting characteristic of the real-world connections made in the Conceptual Discussion frame is that students are more likely to express emotions alongside the RWC made in the Conceptual Discussion frame. This is illustrated by contrasting the two snippets below, both of which were taken from the same group. The first, an example of RWC made in the Worksheet and Procedural Discussion frame, shows the low amount of emotional engagement typically expressed in these frames while the second, an example of RWC made in the Conceptual Discussion frame shows some indicators of the emotional involvement that is more common in this frame.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sarah</td>
<td>yeah.</td>
<td></td>
<td>W</td>
</tr>
<tr>
<td>2</td>
<td>Jennifer</td>
<td>yeah rolling friction's the only (unintelligible) ....</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Jennifer</td>
<td>would going up a hill or down a hill make a difference?</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Frederick</td>
<td>so just say that</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Sarah</td>
<td>because I mean it can't just be a flat thing, or should we just assume that it's a flat road?</td>
<td>1</td>
<td>PD</td>
</tr>
<tr>
<td>6</td>
<td>Jennifer</td>
<td>because..</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Frederick</td>
<td>average, if you average it out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Jennifer</td>
<td>yeah because</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Frederick</td>
<td>just take the average is just like flat road</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

*Table 38: Illustration of RWC in the Worksheet and Procedural Discussion frame.*

In this snippet the students are focused on writing and / or deciding what to write on the page. They do make use of their everyday resources and knowledge around cars to come up with the notion of “a flat road” as being
relevant to energy consumption in a car, but they do not discuss it beyond the
directions to write it down. They make no explicit reference to their emotions
or feelings, and their tone of voice, while dynamic, does not indicate any
particular excitement.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sally</td>
<td>(laughs) and you would... that would.. that would be SLOW</td>
<td>1</td>
<td>CD</td>
</tr>
<tr>
<td>2</td>
<td>Jennifer</td>
<td>that's disappointing!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Sally</td>
<td>that would waste so much time though. like... depends how long the trip is. Saved [7 dollars] driving 10 km slower. What do you know?</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>We can all buy a cookie from. with.</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Frederick</td>
<td>two cookies</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Sarah</td>
<td>(laughs) a seven dollar cookie</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Sally</td>
<td>we can ALL buy one. There's three of us. (laughs) Frederick...</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Sarah</td>
<td>(laughs) Frederick's not...</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Jennifer</td>
<td>poor Frederick.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Sarah</td>
<td>we'll send it to you. we have enough money!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Sally</td>
<td>we can, we can buy Frederick a souvenir. From Disneyland.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Jennifer</td>
<td>(unintelligible comment, sympathetic tone of voice)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Frederick</td>
<td>yes. buy me a keychain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Sally</td>
<td>I was thinking a mickey mouse snowglobe, but a keychain's OK.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Sarah</td>
<td>snowglobe? no. too expensive</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Jennifer</td>
<td>more than seven dollars (laughs)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Sarah</td>
<td>OK.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 39: Illustration of RWC in the Conceptual Discussion and Off-topic frame. The students have just calculated an answer and are commenting on it.

In Table 39 the students are discussing their result. They begin in the conceptual discussion frame by evaluating their result that by driving to
California 10% more slowly they would save $7 in gas fees. The students’ disappointment with that figure is expressed implicitly with laughter, and explicitly by Jennifer’s exclamation on line 2. Sally’s comment on line 1 about their speed in driving also shows an emotional judgment; the tone and meter of their exclamation that “that would be SLOW” demonstrates disappointment or disgust with this prospect. The students then turn to joking about spending their money on cookies.

The fact that students are more emotionally engaged during RWC in the Conceptual Discussion frame makes sense when we consider the fact that these circumstances bring the students’ own knowledge and opinions about the real world into play. Rather than working with knowledge that they have memorized from an outside authority, they are working with their own knowledge. It seems plausible that they might therefore identify more strongly with the results of their discussion, and care more about the contents and consequences of that discussion.

I believe this stronger identification with the results of the discussion is one of the reasons that protracted discussions over assumptions may occur. For example, in one conversation the students discuss what a reasonable typical weight of a car’s driver should be in an extremely protracted fashion and return to haggle over this particular assumption several times. I conjecture that the reason for this is that they actually care about the numbers they are putting down on the page because they are drawing the numbers from their own experience and therefore identify more strongly with them.

6.4.3 Correlation Between Prompts and Conceptual Discussion

In order to examine the research question “To what degree are structured problem-solving methods effective at promoting the use of conceptual and qualitative knowledge at the intended times in the solution process?” I need a way of identifying when students are making use of their conceptual and qualitative knowledge. The epistemological frame of Conceptual Discussion codes times when students are interpreting the meaning of the problem, building an understanding of the physics, or
developing a coherent narrative or visualization of the situation under consideration. While there may be other instances when students make use of their conceptual or qualitative knowledge, the Conceptual Discussion frame captures circumstances when these activities become the focus of the group.

Therefore, I use the Conceptual Discussion frame to measure when the group is making use of their conceptual and qualitative knowledge. To see which steps of the structured problem-solving method promote the use of conceptual knowledge I examine the percentage of time that students spend in the Conceptual Discussion frame during each step. Table 40 below shows the aggregate percentage of time spent in each frame for each prompt for all 14 episodes.

<table>
<thead>
<tr>
<th>Frame</th>
<th>Begin</th>
<th>Interpret</th>
<th>Relevant Physics</th>
<th>Assumptions</th>
<th>Diagram</th>
<th>Solve</th>
<th>Error-checking &amp; Sense-making</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD</td>
<td>6.5%</td>
<td>7.9%</td>
<td>6.4%</td>
<td>7.6%</td>
<td>9.4%</td>
<td>7.0%</td>
<td>7.2%</td>
</tr>
<tr>
<td>PD</td>
<td>18.3%</td>
<td>22.7%</td>
<td>24.6%</td>
<td>26.2%</td>
<td>23.9%</td>
<td>23.9%</td>
<td>17.6%</td>
</tr>
<tr>
<td>W</td>
<td>36.3%</td>
<td>45.4%</td>
<td>41.8%</td>
<td>39.6%</td>
<td>52.5%</td>
<td>54.7%</td>
<td>42.5%</td>
</tr>
<tr>
<td>M</td>
<td>4.4%</td>
<td>1.6%</td>
<td>0.0%</td>
<td>0.5%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>O</td>
<td>15.1%</td>
<td>4.1%</td>
<td>13.4%</td>
<td>10.4%</td>
<td>11.0%</td>
<td>5.0%</td>
<td>22.4%</td>
</tr>
<tr>
<td>TA</td>
<td>19.4%</td>
<td>18.3%</td>
<td>13.7%</td>
<td>15.6%</td>
<td>3.3%</td>
<td>9.4%</td>
<td>10.4%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 40: Aggregate percentage of each problem-solving step spent in each Frame. This is calculated as (Total time in frame during this prompt for all groups) / (Total time spent in this prompt for all groups).

The highlighted row in Table 40 shows the average amount of Conceptual Discussion during each problem solving step, which varies from 6-9%. An ANOVA analysis between all 14 groups shows no statistically significant variation in Conceptual Discussion between the different prompts, even when controlling for High vs. Low RWC. We also see that the average percentage of Conceptual Discussion is well below the best-case benchmark of 38%.
The fact that the rate of Conceptual Discussion is statistically identical across all of the problem solving steps demonstrates that the structured problem solving prompts used in Physics 100 elicit the same level of students’ conceptual and qualitative knowledge. Given that some of the prompts are explicitly intended to promote the use of such knowledge, the constant level of Conceptual Discussion across all of the prompts shows that this intended purpose is not achieved.

6.4.4 Correlation Between Prompts and RWC

In order to examine whether any of the problem-solving steps are effective at promoting students’ Real-World Connections, we next examine the number of RWC made during each step. As noted in Section 6.4.2.3 above, the student groups had a very high variation in the number of RWC and were categorized as High RWC (N=6, 32 or more RWC per episode) and Low RWC groups (N=8, 18 or less RWC per episode). In this section, I analyze both the number and frequency of RWC for these two categories of groups across the problem-solving steps. Looking at the overall number of RWC is better for describing what the students are doing, but looking at the frequency of RWC is better for arguing that some of the prompts actually promote RWC more than others.

Table 42 and Figure 17 below summarize the total number of RWC for the different prompts, broken down by High and Low RWC categories.
<table>
<thead>
<tr>
<th></th>
<th>Begin</th>
<th>Interpret</th>
<th>Relevant Physics</th>
<th>Assumptions</th>
<th>Diagram</th>
<th>Solve</th>
<th>Error-checking &amp; Sense-making</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High RWC Group</strong></td>
<td>25</td>
<td>19</td>
<td>12</td>
<td>89</td>
<td>20</td>
<td>88</td>
<td>13</td>
<td>266</td>
</tr>
<tr>
<td><strong>Low RWC Group</strong></td>
<td>14</td>
<td>13</td>
<td>11</td>
<td>21</td>
<td>4</td>
<td>9</td>
<td>15</td>
<td>87</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>39</td>
<td>32</td>
<td>23</td>
<td>110</td>
<td>24</td>
<td>97</td>
<td>28</td>
<td>353</td>
</tr>
</tbody>
</table>

Table 41: The Total number of RWC by prompt for the High and Low RWC categories. The High RWC groups have 32 or more RWC (N=6). The Low RWC groups have 18 or fewer RWC (N=8).

![Boxplot of number of RWC per group by problem-solving step for the High RWC groups (32 or more RWC, N=6 groups) and the Low RWC groups (18 or less RWC, N=8 groups).]

Figure 17: Boxplot of number of RWC per group by problem-solving step for the High RWC groups (32 or more RWC, N=6 groups) and the Low RWC groups (18 or less RWC, N=8 groups).
Analysis of variance across the prompts shows that the average number of RWC in Assumptions prompt and Solve prompt for the High groups is significantly larger than the number of RWC in every other prompt and for every prompt for the Low groups (p<0.05). There is no statistically significant variation in the number of RWC across the prompts for the Low groups.

The higher number of RWC in the High groups is of course unsurprising. However, Figure 17 shows us where the High groups are making most of their RWC: namely prior to even reading the problem solving steps (marked as Begin) and in the Assumptions and the Solve Prompts. The high number of RWC in the Assumptions prompt is not surprising, as this prompt often requires students to make use of their real-world knowledge in order to make realistic assumptions. However the high number of RWC in the Solve prompt is surprising, as is the low number of RWC in the Sensemaking / Error-Checking prompt where students are explicitly prompted to make use of their real-world knowledge to check their answer. The RWC in the Assumptions, Solve, and Sensemaking prompts are investigated in more detail in the following sections.

6.4.4.1 RWC in the Assumptions Prompt

The high number of RWC in the Assumptions prompt suggests that requiring students to make assumptions in order to complete the recitation problem is effective at inducing some of the students to discuss and make use of their real-world knowledge. The fact that the median number of RWC during this prompt for the High group is close to 15 indicates that these students are doing more than just making a single assumption and moving on, but rather are discussing and debating their assumptions at some length.

It is important to note that this effect is not strictly due to the Assumptions prompt, but also reflects the classroom norms and practices that support the use of assumptions in physics problem-solving such as the use of assumptions in lecture, explicit discussion of their importance in modeling, and the practice sessions that have enabled students to practice making Assumptions.
There are two other ways to examine the RWC data that support the hypothesis that the Assumptions prompt is effective at promoting RWC for the High RWC groups. Firstly, examination of the RWC per unit time shows that the Assumptions prompt has a much higher rate of RWC per minute than other prompts. (See Figure 18 below)

![Boxplot of frequency of RWC by problem-solving step for the High RWC groups (32 or more RWC, N=6 groups) and the Low RWC groups (18 or less RWC, N=8 groups).](image)

**Figure 18:** Boxplot of frequency of RWC by problem-solving step for the High RWC groups (32 or more RWC, N=6 groups) and the Low RWC groups (18 or less RWC, N=8 groups).

Analysis of Variance and Tukey Honest Squared Difference post-hoc pairwise comparison shows that the frequency of RWC in the Assumptions prompt for the High group is higher than the frequency of RWC for the Sensemaking, Diagram, and Interpret prompts of the High group and is higher than the frequency of RWC for all prompts for the Low group (p < 0.01 for all comparisons except Assumption_HI>Diagram_HI, which as p<0.05). There are no other significant differences in RWC frequency.
Looking at the data from this perspective clearly shows that, when the High RWC groups are working on the Assumptions prompt, they make more RWC at a higher rate than in any other prompt. This supports our earlier conclusion that the assumptions prompt is effective at promoting RWC during problem solving, but only for some student groups.

I also examine the pattern of RWC as a function of time after students reach the Assumptions prompt to see how long after reaching the prompt the students make these RWC. (See Figure 19 below)

![RWC after Assumptions Prompt](image)

*Figure 19: Total number of RWC as a function of time after the Assumptions prompt by High and Low RWC groups. The shaded background shows the fraction of groups that are still working in the Assumptions step at that time.*

Figure 17 shows that for both groups the peak of discussion of RWC occurs within a few minutes of reaching the prompt and then decays afterwards. The presence of a peak and its proximity to the prompt are consistent with the idea that the Assumptions prompt actually does induce the students to discuss RWC.
6.4.4.2 RWC in the Solve Prompt

The high number of RWC in the Solve prompt is surprising, as I had expected that students would spend their time during this prompt focused on the details of their calculation. However the High group makes just as many RWC during this prompt as they do during the Assumptions prompt.

One plausible theory to explain the High group’s large number of RWC in the Solve prompt and low number of RWC in the subsequent Sensemaking prompt is that they conducted checks of the real-world plausibility of their work as they went along during the Solve prompt, and therefore had nothing meaningful to add when they subsequently reached the Sensemaking prompt. To investigate this theory I looked at the pattern of RWC over time in the Solve prompt.

![RWC after Solve Prompt](image)

**Figure 20:** Total number of RWC as a function of time after the Solve prompt by High and Low RWC groups. The shaded background shows the fraction of groups that are still working in the Solve step at that time.

In contrast to the graph of RWC after the Assumptions prompt, Figure 20 shows periodic high levels of RWC throughout the Solve prompt for the High
group. This supports the notion that the High group is spontaneously checking their results as they go along.

Table 43 below shows an example of this behavior, which was typical of many of the groups in the High group. In this snippet, the group is working on a calculation to find the force on a vehicle occupant during a car crash. Immediately upon reaching their result they evaluate it in terms of the real-world consequences of exceeding the recommended force.
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gordon</td>
<td>Equals - the mass is 100 kg you assume?</td>
</tr>
<tr>
<td>2</td>
<td>Michael</td>
<td>Yeah</td>
</tr>
<tr>
<td>3</td>
<td>Kirk</td>
<td>Oh he’s gonna get messed up</td>
</tr>
<tr>
<td>4</td>
<td>Michael</td>
<td>(laugh)</td>
</tr>
<tr>
<td>5</td>
<td>Gordon</td>
<td>that’s like over two times what he’s supposed to be getting. He’s just gonna be like, “Oh my God!”</td>
</tr>
<tr>
<td>6</td>
<td>Kirk</td>
<td>But, it’s because you made him so big</td>
</tr>
<tr>
<td>7</td>
<td>Michael</td>
<td>Dude, if he was half that size he’d get</td>
</tr>
<tr>
<td>8</td>
<td>Kirk</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>Michael</td>
<td>Well, think about it</td>
</tr>
<tr>
<td>10</td>
<td>Kirk</td>
<td>Well he’d get - but not as much</td>
</tr>
<tr>
<td>11</td>
<td>Michael</td>
<td>50 times 9.65 is more than</td>
</tr>
<tr>
<td>12</td>
<td>Kirk</td>
<td>But not as much</td>
</tr>
<tr>
<td>13</td>
<td>Michael</td>
<td>The doc said no</td>
</tr>
<tr>
<td>14</td>
<td>Kirk</td>
<td>he’s getting straight plowed</td>
</tr>
<tr>
<td>15</td>
<td>Michael</td>
<td>He’s getting straight plowed!</td>
</tr>
<tr>
<td>16</td>
<td>Gordon</td>
<td>All right, so 965 Newtons</td>
</tr>
<tr>
<td>17</td>
<td>Michael</td>
<td>964 Newtons</td>
</tr>
<tr>
<td>18</td>
<td>Isaac</td>
<td>I got 950</td>
</tr>
<tr>
<td>19</td>
<td>Michael</td>
<td>You got 900 what?</td>
</tr>
<tr>
<td>20</td>
<td>Isaac</td>
<td>50</td>
</tr>
<tr>
<td>21</td>
<td>Michael</td>
<td>so what’s x_i ?</td>
</tr>
<tr>
<td>22</td>
<td>Kirk</td>
<td>and it’d be like, this guy is gonna break every rib in his body. It’s like this guy exceeding his force, the recommended force</td>
</tr>
</tbody>
</table>

Table 42: Example of spontaneous use of real-world knowledge to interpret the result of a calculation.

Kirk’s comment on line 6 “it’s because you made him so big” refers back to these students’ earlier discussion about the appropriate assumption for a person’s mass. This exchange shows that they are spontaneously applying their real-world intuition to their result as soon as they calculate the result, rather than waiting for the Sensemaking and Error-Checking frame.
Not all of the RWC during the Solve prompt are evaluations of the results of calculations. Other clusters of RWC during the Solve prompt occur in episode 14 when students realize they need to make another assumption and in episode 11 when the students engage in a humorous (Off-topic) conversation about how they would spend the $7 they would save on gas. However, these are in the minority and so overall the practice of evaluating and discussing results as soon as they are calculated accounts for the very high number of RWC that the High group shows in the Solve prompt.

6.4.4.3 RWC in the Sensemaking Prompt

The low number of RWC in the “Sensemaking and Error-Checking” prompt for both groups is surprising. Perhaps more than any other, I expected that here students would compare their results to their intuitions and experiences from everyday life. However, there is an equally low number of RWC here for both the High and the Low group.

The pattern of spontaneous evaluation of results during the Solve prompt discussed in the section 6.4.4.2 above helps to explain the low number of RWC in the Sensemaking and Error-Checking prompt. Examining the students’ discussions during these two prompts shows that by the time they reach this prompt, the High group has already done the sensemaking that they feel is necessary. They do not authentically engage in the task of assessing the correctness and understanding the meaning of their result during the Sensemaking prompt, but instead go through the motions of trying to write something down that they feel will satisfy the professor.

The Low group responds similarly. Below are two examples of how one of the Low groups and then one of the High groups responds to the Sensemaking prompt.
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Zoey</td>
<td>So, our units are fine?</td>
</tr>
<tr>
<td>2</td>
<td>Carey</td>
<td>(laughs) everything is fine!</td>
</tr>
<tr>
<td>3</td>
<td>Everyone</td>
<td>(laughs)</td>
</tr>
<tr>
<td>4</td>
<td>Zoey</td>
<td>Well makes sense. Umm money amount – reasonable.</td>
</tr>
<tr>
<td>5</td>
<td>Beth</td>
<td>Yeah.</td>
</tr>
<tr>
<td>6</td>
<td>Beth</td>
<td>The equations are cool.</td>
</tr>
<tr>
<td>7</td>
<td>Everyone</td>
<td>(laughs)</td>
</tr>
<tr>
<td>8</td>
<td>Beth</td>
<td>Fair enough. The units are appropriate for this.</td>
</tr>
</tbody>
</table>

**Table 43**: Snippet from the Error-Checking and Sensemaking step for one of the Low RWC groups, illustrating the cursory consideration of the sensibility of answers that is typical of the data in this study.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Julia</td>
<td>Okay. To check the answer... Are we gonna go... Would we...</td>
<td></td>
<td>W</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[ unrelated conversation about another part of the tutorial ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Nicole</td>
<td>[…] just say our solution would make sense cause it's known, because like traveling slower at highway speed is more fuel efficient.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Nicole</td>
<td>But our calculations...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Lisa</td>
<td>Or just say our results seem reasonable.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Julia</td>
<td>Our results seem reasonable because...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Lisa</td>
<td>[unintelligible] calculation heavy.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Julia</td>
<td>Yeah, it's a heavy duty calculation. Show that [unintelligible] is more fuel efficient. [unintelligible] commonly known.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Lisa</td>
<td>But yeah, just that...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Nicole</td>
<td>And then also say that...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Lisa</td>
<td>The amount he saves seems like a reasonable amount. Not astronomically high, and it's not like [unintelligible] small. So...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Oscar</td>
<td>Just enough [unintelligible]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 44**: Snippet from the Error-Checking and Sensemaking step for one of the High RWC group, illustrating a cursory consideration of the sensibility of answers.
Despite the fact that the first snippet is from a Low RWC group and the second is from a High RWC group we see very little difference in their approach to the Error-Checking and Sensemaking step. These students do not engage in any thorough examination of the sensibility of their answer, but just agree that the answer “seems reasonable” or “makes sense.”

In general, there is little difference between the approach that the High group and Low group use during this step.

### 6.4.4.4 Summary

My analyses show that students in the High RWC groups make significantly more RWCs in the Assumptions and Solve prompts than in other prompts. This supports the idea that the Assumptions prompt is effective at promoting some students’ use of their real-world knowledge. The high number of RWC in the Solve prompt and surprisingly low number of RWC in the Sensemaking / Error-Checking prompt can be explained by the observation that the High RWC groups make use of their real-world knowledge to evaluate their answers immediately upon calculating them rather than waiting for the Sensemaking prompt to tell them to do so. By the time they reach the Sensemaking / Error-Checking prompt these students have nothing more to add, and so merely repeat what they have already decided rather than figuring out anything new.

The number and rate of RWC for the Low RWC groups has no statistically significant variation across the prompts. This demonstrates that only some of the students respond to these different prompts.

### 6.4.5 Analysis of Negative RWC

Not all of the RWC coded were assumed to evidence a positive connection between physics and the real world. Over the 14 episodes coded for RWC, there were a total of 38 RWC identified as being explicitly or implicitly negative about the realism of the recitation problem. These codes represent instances where students complain to each other about the realism of the problem context, values or
assumptions within the problem, or the reasonableness of the tasks that they have been asked to do.

There are several reasons to believe that these spontaneous comments give us a much more honest picture of students’ beliefs than interview responses. These comments are un-prompted, directed to their peers (rather than an interviewer), and are made despite the fact that they don’t help with the ostensible task at hand (the recitation problem). I think that these are often “venting” of students’ repressed opinions, and serve the social purpose of soliciting validation for these opinions which are clearly not sanctioned by authority in this context. I also believe it is important to attend to these expressions because they often reflect the student’s opinion of the recitation problem as a whole. A group of students may make many positive real-world connections over the course of performing the tasks required by a recitation problem, but as we will show below, their negative real-world connections may reflect their opinion of the recitation and those tasks as a whole.

The negative RWC coded for the fourteen episodes are summarized on Table 45 below.
<table>
<thead>
<tr>
<th>Episode</th>
<th>Begin</th>
<th>Interpret</th>
<th>Relevant Physics</th>
<th>Assumptions</th>
<th>Diagram</th>
<th>Error-Checking &amp; Sense-making</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>High RWC Groups</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Low RWC Groups</td>
<td>11</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12</strong></td>
<td><strong>15</strong></td>
<td><strong>3</strong></td>
<td><strong>2</strong></td>
<td><strong>4</strong></td>
<td><strong>2</strong></td>
<td><strong>38</strong></td>
</tr>
</tbody>
</table>

*Table 45: Number of negative RWC broken down by episode number and problem solving prompt.*

We can see from Table 45 that the negative RWC occur primarily in the beginning of the recitation when students are still reading the question and interpreting what it is asking. This fits with the picture of negative RWC as a judgment of the recitation as a whole that occurs spontaneously when the students read the problem. We can also see that there is a large variation in the number of negative RWC by group.

These 38 negative real-world connections listed in Table 45 were grouped into 17 clusters. A cluster of negative real-world connections was determined by examining the transcript and looking at the topic of conversation when those negative real connections were made. Negative real-world connections from the same conversational thread were considered to be a part of the same cluster.
Upon review of the substance of conversations and the negative real-world connections, six general categories of negative real-world connection were identified, which are described below. However, I do not make the claim that these constitute different types of behavior that are in some way cognitively or epistemologically distinct. Rather, I argue that these six categories offer us different views of the various aspects of circumstance that students mention when expressing their frustration. The explicit content of their speech is illuminating and may inform future design of instructional tasks, but might not reflect the true source of the students’ frustration.

6.4.5.1 Detail of Tutorial (4 clusters)

This cluster of negative real connections were motivated by the students’ objection to a particular detail of the problem, typically a numerical value. In the transcript below, one group discusses their interpretation of the problem’s statement that a car’s stopping distance is 20 m.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shary</td>
<td>There’s no way you- people stop going that fast in 20m. So it means you’re supposed to take 20m to stop?</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>William</td>
<td>At 50km an hour</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Shary</td>
<td>That’s ridiculous! Isn’t that ridiculous? That seems way too long.</td>
<td>-1</td>
</tr>
<tr>
<td>4</td>
<td>William</td>
<td>Too long?</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Virginie</td>
<td>20 meters?</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Shary</td>
<td>Yeah. 20 meters isn’t that quite far?</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Virginie</td>
<td>Yeah it is</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>William</td>
<td>I’m really bad with distances so</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Virginie</td>
<td>Oh actually no. It’s not very far. It's not</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>William</td>
<td>Oh so that’s like an average</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Virginie</td>
<td>Cause I run 30 meters at track practice and it’s not far.</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 46: Transcript of negative RWC cluster based on objection to a detail of the tutorial. These students have just read a recitation problem that states the minimum stopping distance for a car traveling 50 km/h is 20 meters. A “−1” in the RWC column indicates a statement that was coded as a negative RWC, while a “1” indicates a positive RWC.
In another example, one student expresses her opinion that the concept of constant acceleration is inappropriate for a braking car.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Georgia</td>
<td>see that doesn't make sense though. see, you know like, that doesn't mean it's constant acceleration if it's stepping on the brake. you know what I mean, it's like the car's decelerating, this is a constant acceleration question, it doesn't make sense</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>Hannah</td>
<td>it's decelerating...</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Georgia</td>
<td>yeah I don't decelerate like that though. Let me tell you! (makes screech noise) (laughs)</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 47: Transcript negative RWC cluster based on objection to a detail of the tutorial. These students are discussing the assumptions for their model. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.

In both of the above situations, a student expresses an opinion that a particular value or assumption in a problem is unrealistic. This distinguishes these negative RWC from the next category, which deal with criticism of the motivation for the calculation required in the problem.

6.4.5.2 Motivation for Calculation (6 clusters)

In this category are negative comments about the realism of the recitation problem’s motivation for calculation. For example, one problem stipulates that a fridge must be tied in the back of a pickup truck using only 2 tie points and a single length of rope. Many students quite sensibly commented that this scarcity of rope was unrealistic, and that if they were concerned about having enough rope to tie down a fridge that they would go to the store and buy more rope. The scarcity of rope was intended as a feature to motivate quantitative calculation but the students perceived it as an artificial and unrealistic restriction.
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rafael</td>
<td>so we tie the rope in two places.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Tony</td>
<td>in two places, cause he doesn't have enough rope, cause he's cheap.</td>
<td>-1</td>
</tr>
<tr>
<td>3</td>
<td>Rafael</td>
<td>what does that mean, tie the rope in two places?</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Tony</td>
<td>It means that Physicists don't have enough rope.</td>
<td>-1</td>
</tr>
<tr>
<td>5</td>
<td>Rafael</td>
<td>so if he had enough rope, he would tie it in more than two places</td>
<td>-1</td>
</tr>
<tr>
<td>6</td>
<td>Tony</td>
<td>In 18 million places like everyone else who owns a pickup, and not</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>screw up, and not have a collision, and not, you know, have a few</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>beers while moving, and then drive.</td>
<td></td>
</tr>
</tbody>
</table>

Table 48: Transcript of example negative RWC cluster based on objection to the motivation for a calculation. These students have just read a recitation problem that states that a fridge will be secured in the back of a pickup truck with exactly two ropes. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.

A second example shows the students objecting to a recitation problem in which a doctor has prescribed that a patients avoid more than 450 N of force on their broken rib. This recommendation is used as a motivation for calculation but the students quite sensibly complain that doctors do not typically communicate with their patients in terms of Newtons, nor are they in the habit of conducting physics calculations in order to determine the maximum safe load for a broken rib.
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gordon</td>
<td>So we must determine (pause) if the um</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Michael</td>
<td>If greater than 450 Newtons of force</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Kirk</td>
<td>Why would a doctor say?</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Michael</td>
<td>Yeah I know. (laugh) The doctor’s like, “listen ok let me do some quick math. V 2 minus Vf over a square root of that.</td>
<td>-1</td>
</tr>
<tr>
<td>5</td>
<td>Isaac</td>
<td>(laugh)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Michael</td>
<td>So you’re going to need to avoid 450 Newtons of force or greater on your chest with this broken rib.</td>
<td>-1</td>
</tr>
<tr>
<td>7</td>
<td>Isaac</td>
<td>(laugh)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Michael</td>
<td>yeah. “Good thing I majored in physics before I went to med school!”</td>
<td>-1</td>
</tr>
<tr>
<td>9</td>
<td>Gordon</td>
<td>Force would be</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Isaac</td>
<td>Or, “it’s a good thing they made me take Physics 100”</td>
<td>-1</td>
</tr>
<tr>
<td>11</td>
<td>Michael</td>
<td>And 101! Actually and 101!</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Isaac</td>
<td>And 101</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Gordon</td>
<td>On his chest</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Kirk</td>
<td>I don’t have to take 101</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Isaac</td>
<td>before I got in to med school!”</td>
<td></td>
</tr>
</tbody>
</table>

Table 49: Transcript of example negative RWC cluster based on objection to the motivation for a calculation. These students have just read a recitation problem in which a doctor has advised the patient to avoid more than 450 Newtons of force on their broken rib. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.
A third example, below, shows students’ objection to the problem being about moving a fridge

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Igor</td>
<td>Yeah why would you have to move a fridge anyway? It's not like this is Montreal It always comes with the place. I guess maybe</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>Winifred</td>
<td>I think it's a bylaw that to rent out a suite you have to have a fridge</td>
<td>-1</td>
</tr>
<tr>
<td>3</td>
<td>Igor</td>
<td>Not in Quebec</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Winifred</td>
<td>yeah not in Quebec. But here. It is.</td>
<td>-1</td>
</tr>
<tr>
<td>5</td>
<td>Igor</td>
<td>Yeah they're making a big assumption that our friends are independently wealthy and have like, you know aren't renting (laughs)</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 50: Transcript of example negative RWC cluster based on objection to the motivation for a calculation. These students are discussing the assumptions necessary to solve a problem involving moving a fridge. A “−1” in the RWC column indicates a statement that was coded as a negative RWC, while a “1” indicates a positive RWC.

This example is interesting because the students’ objection relies on their own experiences with moving. Considering that students typically rent their apartments and a fridge is provided with any rental, they object to the notion of moving a fridge. From the perspective of a homeowner moving a fridge might seem less problematic, but to these students it is unrealistic. This example reinforces the notion that we need to pay attention to the circumstances of students’ actual lives in order to promote positive real-world connections.

6.4.5.3 Physics Vs. Common Sense (1 cluster)

One group commented specifically how they felt that it was unrealistic to use physics knowledge to solve everyday problem rather than using common sense. The transcript of this cluster is listed below.
Tony’s comment on line 2 about how he “wouldn't be feeling very safe” suggests he would not feel confident enough in his skill in physics to make a decision that could be potentially life-threatening. His follow-up comment that “I think common sense works better than physics in most situations in life” demonstrates a clear opinion regarding the utility of physics in the real world. In this cluster, students are not complaining about a particular feature of a particular problem but rather are expressing an overall belief that commonsense intuition is more appropriate for everyday problems than physics.

6.4.5.4 Relevant Experience (1 cluster)

One group, upon reaching the “error-checking and sensemaking” prompts, had the following complaint.
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Winifred</td>
<td>Just last week I was in a car accident with my friend and a truck and a mini-fridge, and what do you know? I saw it, and now ICBC. No problem.</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 52: Transcript of example negative RWC cluster based on objection to the suggestion that students would have experience with which to judge their answer to a problem that involves moving a fridge, where the truck carrying the fridge may crash. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.

This comment was delivered in a sarcastic tone of voice and prompted a round of laughter from the group, indicating that statement was intended to be (and was received as) humorous. The tone of voice and subsequent laughter indicate that students feel that this statement is absurd. They have interpreted the problem’s prompt to consider their everyday experiences to check their results to mean that they ought to have experience with a situation exactly like the one described in the problem. Because this problem is about a pickup truck carrying a fridge in the back that has an accident, the students assume that the only everyday knowledge that would be useful for checking the results of the physics calculation is experience with precisely that situation, which they find ridiculous.

Even though it was only expressed by one group, this comment is interesting because it reflects an attitude towards sensemaking that is very different from what the professor's intent. The professors hope the students will be able to creatively construct ways to make use of their existing knowledge to draw comparisons to their result. However, because the students believe it is necessary that they will have had an experience that is precisely analogous to the recitation problem, they never attempt to do meaningful sensemaking. This suggests we pay closer attention to students beliefs and practices around the act of checking their answer.

This example makes it clear that students’ beliefs about the nature of sensemaking and the knowledge required can be unproductive and forestall
meaningful exploration of the relevance of everyday knowledge and intuition to physics.

6.4.5.5 Interpretation of Goal (2 clusters)

The problem about calculating forces in the ropes that tie down the fridge implies that students should consider the case of a car crash and then asks “is it safe to drive home?” This way of phrasing of the question is intended to allow student groups to do the work of operationalizing the concept of “safe to drive” in terms of physical quantities. Two student groups commented that they felt was it logically inconsistent to ask whether it was safe considering that one possibility was that you would get in an accident. One of these clusters is reproduced below.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shary</td>
<td>It’s hard to say if it’s safe or not though because you can’t predict the future. You can’t predict what’s going to happen (laugh), how do you like-</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>Virginie</td>
<td>Like if there was an accident or not right?</td>
<td>-1</td>
</tr>
<tr>
<td>3</td>
<td>William</td>
<td>Exactly. If you’re in an accident yeah it’s probably not safe but.</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(laugh)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Everyone</td>
<td>(laugh)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Shary</td>
<td>But if you’re not in an accident and you’re driving</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Virginie</td>
<td>It’s never safe when you’re in an accident!</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 53: Transcript of example negative RWC cluster based on judgment that the goal of the tutorial is unrealistic. These students are discussing the recitation’s instruction to consider whether it is “safe to drive home”. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.

Because the students feel that “it's never safe when you're in an accident” they feel that the question of whether it’s “safe to drive home” is unrealistic.

6.4.5.6 Vaguely Negative (3 clusters)

The last category of negative RWC is those that are negative without expressing exactly why. One example is given below.
<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Quote</th>
<th>RWC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(flipping)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Katrina</td>
<td>Why don't we assume this problem doesn't make sense</td>
<td>-1</td>
</tr>
<tr>
<td>3</td>
<td>Joy</td>
<td>assume we'll never have to see this problem in real life. Done.</td>
<td>-1</td>
</tr>
</tbody>
</table>

*Table 54: Transcript of example vaguely negative RWC cluster. These students have been flipping through their notes searching for other assumptions to make for their recitation problem. A “−1” in the RWC column indicates a statement that was coded as a negative RWC.*

In this example, the students’ comments imply that they feel the problem is unrealistic or unlikely to be encountered, but they don’t say why. We can assume that those judgments are being made based on the students’ real-world resources, but we can’t say why they have judge the problem unrealistic.
7 DISCUSSION AND CONCLUSIONS

7.1 Research Question 1: Impact of Physics 100 Reform on Student Beliefs

As described in chapter 3, students’ scores on the Overall and Real-World Connections category of the CLASS survey did not improve after the course transformation. This suggests that an emphasis on presenting physics in real-world contexts is not sufficient for improving students’ overall attitude towards the relevance of physics to the real world.

7.1.1 Discussion

I have a few conjectures that might explain the lack of improvement on the CLASS survey scores. Firstly, it is possible that the instructors’ (and my) perception of what constitutes a “real-world context” is substantially different from the students’. While we may believe ourselves to be presenting physics in a context that is familiar and plausible to the students, the interview results from chapters 4 and 5 suggest that this may not be the case. It remains to be seen, however, how important this mismatch in judgment of real-world relevance might be to students’ perception of the course and of physics in general.

Secondly, it is possible that the epistemological focus of the pedagogy is much more important than the context of the problems and examples for promoting students’ perception of relevance. Redish and Hammer [17] have demonstrated improvements in students’ scores on the MPEX (a survey of students’ attitudes and beliefs that is closely related to the CLASS [13]) without focusing exclusively on presenting physics in an everyday context. Instead, their curriculum focuses on students’ epistemologies (their ways of judging and developing knowledge) and explicitly discusses techniques for bridging between the everyday ways of developing new knowledge and the disciplinary ways of developing new knowledge used in physics. As well, Brewe, Kramer, and O’Brien have shown that their “Modeling” curriculum for introductory physics, which does not exclusively work with real-world contexts but highlights the disciplinary epistemology of model development in
physics, improves their students’ Overall CLASS scores although not in the Real-World Connections category [18].

The positive impact of the two above-mentioned pedagogies on surveys of students’ beliefs suggest that explicit attention to negotiating between students’ and physicists’ epistemologies is required in order to positively affect their beliefs about the relevance of physics to the real world. While I do not have direct data on whether the Physics 100 instructors’ presentation of the epistemology of physics changed along with the course content during the course transformation, my impression as a participant in the course development and occasional attendee in the lecture sessions is that it did not. The lack of improvement on the CLASS scores in Physics 100 may be due to the lack of emphasis on how physics and physicists develop and judge knowledge and how to negotiate between these practices and those in the everyday realm.

7.1.2 Positive Impacts of Course Transformation

Despite the lack of improvement in the CLASS results, the instructors’ reports of their interactions with students during lecture suggest some ways that students’ beliefs and approach to the course may have been improved by the course transformation. For example, one instructor reported that he felt the students were more engaged, asked more questions and displayed more interest when discussing issues such as climate change and energy production. It is his feeling that these topics may have engaged the interest of students who do not identify as being interested in physics, but are concerned with these broader societal and environmental issues. While the discussion of these topics did not significantly influence the students’ CLASS scores overall, there may have been an important impact on the students who did have a stronger interest in societal and environmental issues.

Another positive outcome of the course changes was that the instructors’ teaching evaluation scores improved. While these may only represent a measure of how much students like the course, it seems that the students liked the course better after it had been changed to include an explicit emphasis on everyday contexts and broad societal issues.
The students’ discourse during the recitations shows another benefit to using explicit real-world contexts in the course. Examination of the Real-World Connections made during the Solve prompt shows that students are making use of their real-world knowledge to interpret and evaluate their answer. Because these problems are set in a context with which the students have some experience, they are able to compare the features of their model and the results of their calculations to their own experience. This comparison might not be possible for problems that are set in an unfamiliar context (such as Antarctica) or in an abstract context (such as blocks-on-planes). The fact that more than one student in each group is likely to be familiar with the problem context also enables the kind of back-and-forth discussion observed in some of the groups.

7.2 Research Question 2: Types of Real-World Connection

This dissertation examines two main ways that students make connections between physics and the real world. The first is in their judgment of the relevance of particular problems or aspects of instruction to their real world. The second is via their use of real-world resources in a physics context. These two types of connection are discussed below.

7.2.1 Judgment of Relevance

As described in chapter 4, students cite several different ways that physics can be relevant to the real world. Students from Physics 100 who had been exposed to the environmental issues in the curriculum discussed the relevance of physics in terms of its connection to these issues. Some expressed a belief that physics is broadly relevant to phenomena in the real world, while distinguishing that it is not something they think about in their daily lives.

Students’ responses in chapter 4 make it clear that the sense of “real-World Connection” is not a single dimension but rather covers a wide range of different beliefs which interact with the student’s personal history in idiosyncratic ways. This diversity suggests that seeking a single construct of “Connection” or “Relevance” may be problematic.
In chapter 6 I identified five different ways that students make use of their real-world knowledge in physics problem solving, two of which tell us something about students’ perception of the relevance of their physics problems to the real world. Firstly, I identified Meta-statements, which were explicit statements of judgment of the relevance, realism, or likelihood of the problem situation under discussion. Secondly I identified instances where students personalized the physics problems by fleshing out the problem circumstances with their knowledge of the real world. While students who personalize physics problems may not explicitly judge the problem under consideration to be relevant to the real world, by bringing in their real-world knowledge to bear on the physics problem they are showing that there is, at the very least, some intuitive connection.

7.2.2 Use of Real-World Resources in Physics

In addition to the above judgments of relevance, students also make use of real-world resources in a physics context to make assumptions, to interpret of the meaning of abstract representations, and to evaluate the results of their calculations. These three types of Real-World Connection are similar in that they involve making use of real-world resources in a productive manner during problem solving.

7.2.3 Discussion

Students’ conceptions of the ways that physics is connected to the real world are very diverse and exhibit many nuanced distinctions. For example, some students distinguished between “connected” to the real world and “relevant” to the real world. Their judgment of what constitutes relevance can be influenced by a variety of factors as discussed in Section 7.3 below. Students also distinguish between relevance to themselves and to others.

One conjecture about what makes a particular topic relevant to a particular student is that it has meaningful consequences for them. If a student says that a problem is relevant to the real world but not to themselves, this may be because they believe the problem has consequences for others but not for themselves.
The realization of students’ diverse conceptions of real-world connections in physics changed the way the Physics 100 instructors saw their students and their teaching and has implications for anyone who wishes to promote real-world connections in their class. Recognizing the diversity of students’ interpretations motivates a more diverse and student-centered approach to teaching real-world connections. Rather than assuming that students are all seeing the same kind of real-world connections, we must anticipate this diversity and attend to different aspects of students’ perspectives in our pedagogy. In addition, the diversity of ways that students may make connections between physics and the real world implies that instructors should consider exactly what type of real-world connections they wish to promote.

7.3 Research Question 3: Factors Influencing Real-World Connections

The studies in this dissertation identified several factors that inhibit or promote students’ perception of physics problems as relevant to the real world and several that promote students’ use of their real-world resources within a physics context.

An extremely important factor that influences both students’ perception of relevance and their use of real-world knowledge in a physics context is their individual beliefs about the nature of physics and physics knowledge. For example, many students may share Samantha’s interpretation, described in chapter 4, of “reasoning skills” as being “doing well on the physics exam”. This perspective can significantly frustrate the goal of encouraging students to make real-world connections: it is not sensible to try to understand connections between physics and the real world if you implicitly approach the course from a utilitarian grade-focused perspective.

The evidence of Samantha’s epistemological approach supports Elby’s result that students regard “pursuing good grades” and “trying to understand physics deeply” as being two different things [15]. We also see a similar split in students’ discussions during collaborative problem-solving, which can be divided into Procedural and Conceptual categories. In the Procedural Discussion frame, students are actively concerned with making progress towards the putative goals of the recitation problem, whereas in the
Conceptual Discussion frame they are trying to understand the meaning of what’s going on and, in doing so, make significantly more use of their real-world knowledge.

Other factors that affect students’ perception of the relevance of physics to the real world and that affect students’ use of real-world knowledge in a physics context are discussed in the following sections.

7.3.1 Factors Affecting Perception of Relevance

One overall trend in students’ perception of the relevance of physics to the real world is that students judge relevance to themselves and to others differently. Judgments of relevance to themselves are primarily influenced by their immediate personal circumstances or career goals.

Students are much more engaged and motivated by connections that they perceive to be directly relevant to themselves [81]. An illustration of the importance of personal relevance occurred during a (non-research) interview with a student early in the development of the course. This student complained that he felt the course spent too much time discussing the physics of insulation and its impact on energy consumption in the home and home heating bills. Because he lived at home and his parents paid the heating bill, he felt that this physics was not relevant to him.

This anecdote also helps to illustrate an important consequence of this population’s focus on relevance to their current lives and immediate career goals: students’ conception of a real-world connection is likely to be different than their instructors’. In order to understand how to promote students’ perception of the connection between physics and the real world, we must attend to students directly to understand their lives, interests, and goals.

Below, I have identified several factors that influence students’ perception of the relevance of a problem to their real world. In doing so, I implicitly encourage a framing that suggests a particular problem feature can promote a sense of real-world relevance regardless of the instructional environment or the student. However, my studies have clearly highlighted the importance of the instructional context as well as the students’ particular epistemologies. The responses given by students interviewed
within the context of Physics 100 suggest that they way they reacted to the real-world issues raised in the interviews was significantly driven by their expectations about Physics 100. Thus, student responses to the interview questions in chapter 5 (which were not associated with a particular course) might not be indicative of how students would respond to these questions in the context of a course. Furthermore, many of the factors that trigger associations are highly idiosyncratic and particular to students’ own histories and interests.

This suggests that it may not be possible to create a problem that will be perceived as relevant for all or even most students. However, the following sections describe the problem features that students are most likely to cite as affecting their perception of connection to the real world, and as such offer the best start on developing problems that students will see as relevant.

### 7.3.1.1 Context

One of the key factors that contributes to students’ perception of relevance to the real world is the context of a particular example or problem. As we saw in chapter 5, familiarity with the context of a problem was one of the triggers that students cited when discussing connections to the real world. In quantitative analysis, problems set in an everyday context were also demonstrated to have a significant correlation with students’ ratings of a problem’s overall connection to the real world.

The importance of setting problems in an everyday context was also highlighted in chapter 4 (see section 4.5.3.2: Interpretation of Realism of Tutorials). For example, Valerie’s comments on the unrealistic and fantastic nature of some of the context-rich problems was an important insight from these interviews because this type of fantastic context is common in many physics problems as well as in the published library of context-rich problems [60]. For example, the mechanics portion of this online archive includes questions based on the following scenarios:
Because of your physics background, you have been asked to check the feasibility of an action movie stunt.

Because of your physics background, you have been able to get a job with a company devising stunts for an upcoming adventure movie being shot in Minnesota. In the script, the hero has been fighting the villain on the top of the locomotive of a train going down a straight horizontal track at 20 mph.

You have been hired as a consultant for the new Star Trek TV series to make sure that any science on the show is correct.

None of these scenarios is likely to be interpreted as “everyday” or “realistic” by a typical introductory physics student. While humorous or fantastic scenarios may be entertaining or memorable, Valerie’s comments suggest they carry the message that physics is neither appropriate nor connected to more everyday situations.

Given that students tend to judge realism based on their immediate circumstances and career goals, this result suggests that instructors who wish to promote real-world connections should eschew problems with this type of novelty context, and instead use problems that students can relate to based on their present lives.

7.3.1.2 Consequences

Another overall trend in these studies is that students respond more positively if the outcome of the problem is consequential. In chapter 5, we saw that two of the broad categories of triggers that students cite when justifying their judgments of relevance to the real world have to do with the impacts that a particular problem may have on themselves or on society more broadly. Two factors in particular emerged as common examples of relevant consequences: environmental consequences and financial consequences.
**ENVIRONMENT**

One example of a factor that students mentioned as influencing their judgment of relevance to the real world was connection to the environment. Several of the test problems used in chapter 5 were deliberately constructed with direct or indirect environmental themes, and the large number of triggers indicated that some students perceive environmentally relevant problems to be connected to the real world and to themselves. While statistical analysis of the environmental characteristic of problems did not show a significant correlation with students’ ratings of the overall relevance of those problems to the real world, a number of students’ responses indicated that they saw an intimate connection between “connected to the real world” as “relevant to the environment”, suggesting this area might be worthy of further inquiry.

The notion that students do see environmentally related problems as connected to the real world is corroborated by the finding in chapter 4 that students saw connection to environmental issues as one of the main types of connection to the real world. The fact that the environment trigger is also demonstrated in the chapter 5 study which included an extremely diverse group of students (only one of whom has taken the environmentally–themed physics course) shows that the notion of environmental focus as being relevant to the real world is not strictly limited to Physics 100 students. The emergence of this connection between physics, environmental issues, and broad real-world relevance in both the chapter 4 and chapter 5 studies supports the idea that there is an important connection. Further research is needed in order to more fully explore the connection between students’ perception of science and its relevance to environmental issues, the world in general, and themselves.

**MONEY**

Another example of a factor that promoted a perception of relevance was monetary consequences. In chapter 5, problems that were related to saving money were significantly correlated with higher ratings of relevance overall.
Considering that money is quantitative and represents one of our culture’s principal ways of identifying value, it is not surprising that students felt that problems with monetary consequences were relevant to the real world. Pursuing problems in this area is also worthwhile in attempting to structure connections between physics problems and consequences for students’ lives.

7.3.1.3 Quantitative Reasoning

Another factor that affects students’ perception of the relevance of physics problems to the real world is the presence of quantitative reasoning or calculations.

In chapter 5, several students justified their judgment that a particular problem was not relevant to the real world based on the fact that these problems described a person performing unrealistic quantitative calculations in an everyday context. In addition, in chapter 4 Helene stated that physics is “mostly calculations” and that she doesn’t do them in “real life”. The feeling that quantitative reasoning is not realistic in a real-world context was also demonstrated in the analysis of Negative Real-World Connections in Chapter 6.

The Physics 100 recitations, which are set in an everyday context in order to demonstrate the relevance of physics to the real world, attempted to justify the use of quantitative methods via a “cover story” that would provide a motivation for their use. However this strategy is not always successful. For example, in the case of the problem where a doctor is giving advice to his patient in terms of the number of Newtons of force that his rib can withstand, the attempt to improve the realism of the problem by providing a medical context was completely subverted by the students’ observation that the problem is unrealistic because doctors don’t talk in terms of forces (see page 309 in Appendix A for the full problem). Thus, the problem feature intended to motivate the use of a full calculation (the doctor’s advice) is instead perceived by the students as arbitrary and unrealistic. The strangeness of this cover story sends the message that physics calculations really aren’t relevant, subverting the goal of demonstrating the relevance of physics.
In another problem the students are asked whether a fridge that has been tied in the back of a pickup truck will come loose in an accident (see page 316 in Appendix A for the full problem). The cover story of this problem provides a motivation (we want to make sure the fridge won’t come loose), but in order to make the problem computationally tractable the students are restricted to working with a single length of rope and two tie-points. These restrictions were intended to make the problem solvable, but students quite sensibly observe that, once again, they are arbitrary and unrealistic.

**Motivation For Quantitative Calculations**

Students’ belief that quantitative calculations are inappropriate in an everyday environment presents a challenge for the design of quantitative everyday problems.

The difficulty of developing motivations for calculations is not limited to the problems used for this dissertation. The majority of textbook problems, while they might be set in an everyday context, do not provide a realistic motivation for conducting a calculation. Many of the context-rich Problems in the University of Minnesota’s online archive [60] use an arbitrary or unrealistic motivation for calculation such as a “competition” or by stating that the student “wonders” what some quantity will be, a story which will likely ring hollow to a physics student who feels that quantitative calculations are unrealistic in an everyday context.

Part of the reason that it is very common for physics problems to have an unrealistic or absent motivation for calculation is that problems with realistic motivations are likely to be unsuitable as recitation or homework problems. The desire to use problems for homework or recitations means we are constrained to make problems that are quantitative, tractable to an introductory audience, and solvable in a short period of time. In order to achieve these goals we must clearly define the problem and set a goal for calculation. While students can be allowed some latitude in interpreting the goal of the problem or
making some assumptions, if we wish to ensure that they perform the desired
calculation the problem must be adequately constrained to ensure it cannot be
solved (or circumvented) using qualitative methods. If we also want these
problems to be realistic we run into the issue that a clearly defined problem and
goal are in themselves unrealistic.

However, chapter 5 showed that problems having to do with monetary
consequences were rated as being highly connected to the real world, despite
the fact that they involved conducting detailed calculations. I conjecture this is
because monetary consequences are one of the few areas in everyday problem-
solving where people are inclined to optimize for maximum benefit. In many
everyday circumstances, we can solve a problem just by satisfying a certain
condition. For example, it’s not necessary to calculate the minimum number of
strands of rope necessary to hold down cargo in the back of a pickup truck; we
can just tie rope on the cargo down until it doesn’t move, satisfying the
“sufficiently tied down” condition. After this condition is met, further tying
yields no benefit. However, monetary problems always have an incentive to
optimize the solution: saving money is good, but saving more money is better.
This means that the kind of precision afforded by full calculations is rewarded
in real-life financial problems. Indeed research in everyday problem solving
has found that financial calculations are commonly conducted in everyday
shopping activities such as grocery shopping [82].

This suggests several possibilities for improving students’ perception of the
realism of conducting calculations in an everyday setting. Firstly, we might try
using a different format of quantitative calculation other than the typical
homework or recitation problems. Secondly, we might try using financial
consequences as a part of the cover story. These recommendations are
discussed in more detail in section 7.6 below.

7.3.2 Factors Affecting Use of Real-World Knowledge

In chapter 6, I explored factors that influence students’ use of their real-world
resources in the context of their physics recitations. Instances where students’
discourse demonstrates their use of such resources are called Real-World Connections (RWC). The influence of both students’ epistemic framing and the structured problem-solving strategy on students’ RWC was examined.

### 7.3.2.1 Epistemic Framing

Students engaged in collaborative problem solving demonstrated a statistically significant correlation between the Conceptual Discussion frame and a high frequency of Real-World Connections. The Conceptual Discussion frame not only has a higher frequency of real-world connections, but these real-world connections often occur in clusters and the students are often emotionally engaged during these discussions. These data paint a picture of students engaged in back-and-forth conversations where they repeatedly make use of their real world knowledge because they care about the outcome of the discussion. In this frame students are discussing with each other in an engaged way trying to work out something that makes sense.

The fact that students engaged in the Procedural Discussion frame do not have a similarly high frequency of RWC suggests that instructional tasks that promote Procedural Discussion do not necessarily promote the use of real-world resources. If an instructional task is such that students already know how to complete it or spend most of their time discussing how to complete it instead of what it actually means they will be less likely to make use of their everyday knowledge in solving it. Even recitation problems such as those used in Physics 100 that are explicitly set in students’ everyday environment will have a much lower likelihood of promoting RWC if the students do not engage in Conceptual Discussion.

Although epistemological frames can activate or inhibit the use of resources, I do not claim that a frame causes the real-world connections. Indeed, there are some circumstances where a real-world connection seems to induce a change in a person’s framing, and in that sense the real-world connections may “cause” a frame to occur. However, I do argue that while students are in a stable frame, that frame may activate or inhibit their access to
real-world knowledge just as it may activate or inhibit any other resource. I argue that the higher frequency of Real-World Connections that is observed in the Conceptual Discussion frame is the result of this regulation of access to resources.

7.3.2.2 Problem-Solving Strategy

The study in chapter 6 showed that some steps of the structured problem strategy were correlated with higher rates of Real-World Connections. These correlations were only significant for some of the students: the six groups that had the highest number of Real-World Connections (the High RWC groups) made a significantly higher number of those RWC during the Assumptions and the Solve problem-solving steps.

The RWC observed in the Assumptions prompt were discussions of exactly the type intended by the recitation authors: discussions of real-world knowledge to develop and discuss appropriate assumptions. The RWC observed during the Solve prompt were primarily discussions of the sensibility of the calculations that had just been performed.

It is interesting to note that each High RWC group is likely to have a high number of RWC in the Assumptions prompt as well as in the Solve prompt. For at least one of the groups studied it seems that some of the RWC in the Solve prompt are directly related to the RWC that they made in the Assumptions prompt. Further research is necessary to determine whether it is true in general that the RWC in the Solve prompt are in any way the result of prompting students to explicitly articulate their assumptions. Such research could help to further illuminate whether there are any pedagogical reasons for the high number of RWC during the solve prompt.

The low number of RWC in the Sensemaking prompt is also remarkable. The low rates of Conceptual Discussion and RWC in this step suggest that explicitly prompting students to engage in sensemaking as a part of a prescribed problem-solving strategy is not effective, at least within the context of this study.
None of the students studied engage in significantly elevated rates of Real-World Connections during this step. Despite the fact that one of the early recitations offered explicit instruction on a variety of sensemaking techniques and these techniques were modeled during lecture, most students use their unelaborated intuition during this step. This result, combined with the observation of unexpectedly large numbers of RWC during the solve step suggests that student groups either spontaneously use their real-world knowledge to evaluate the sensibility of their answers or do it hardly at all. However, none of the groups followed the printed prompts designed to encourage them to make use of their real-world knowledge.

The results from this study show that the pedagogical practice of requiring students to engage in a Sensemaking step as the part of a structured problem-solving strategy is ineffective at inducing students to make use of their real-world knowledge during that step. While it may still be fruitful to teach and demonstrate such sensemaking practices, requiring students to perform this step seems ineffective at inducing the desired behavior.

7.3.2.3 Generalizing Beyond RWC

One might wonder how this research on students’ use of their real-world knowledge might apply in courses that do not emphasize connections to students’ everyday knowledge. I propose that the factors that influence students’ use of their real-world resources also regulate their use of any knowledge developed outside the course they are currently in. When the Physics 100 students are in a Conceptual Discussion frame, they access a diverse array of resources in order to understand the meaning of the current discussion. I conjecture that students in other physics courses will exhibit similar frame changes and that their use of diverse resources to make sense of new ideas will occur in a Conceptual Discussion frame.
7.4 Research Question 4: Influence of Structured Problem-Solving Methods on Conceptual Discussion

In chapter 6 the study of the rates of Conceptual Discussion in each of the steps of the course’s structured problem-solving strategy revealed that there was no statistically significant variation in the percentage of each step that students spent engaged in Conceptual Discussion. This was surprising considering that the problem-solving strategy had steps that were specifically intended to promote the use of conceptual and qualitative knowledge.

This is a very important result considering the prevalence of recommendations to require students to follow prescribed problem-solving methods. For example, in Knight’s “Five Easy Lessons”, a summary of PER results geared towards physics faculty, the author suggests that use of a prescribed problem-solving strategy “forces students to consider other issues besides ‘find the right formula,’ and with practice this technique aids them in building a coherent knowledge structure” [83]. Heller et al. imply that structured problem-solving methods “help students integrate the conceptual and procedural aspects of problem solving” [1]. However, my results show that requiring students to use a prescribed problem-solving method for quantitative physics problems is ineffective at promoting the use of conceptual and qualitative knowledge at appropriate times during the solution process.

There is no reason to believe our adaptation of context-rich problems and the associated structured problem-solving method was atypical. Therefore, our results are reasonably representative of any instructor that is attempting to adapt a research-based pedagogy for their own circumstances. If our implementation of prescribed problem-solving strategies has some flaw that prevents the strategies from effectively promoting students’ conceptual discussion, then this flaw is likely widespread in other implementations.

This result calls into question the notion that we can teach students expert-like problem-solving strategies by constraining them to behave in expert-like ways. If these methods are ineffective at promoting meaningful conceptual discussion, then students
may never gain practice in making use of conceptual information to guide and structure their problem solution.

While it is not clear from my analysis why the rates of Conceptual Discussion did not vary across the problem-solving steps, I do have a conjecture. Instead of focusing the students on conceptual aspects of the problem solving process, the worksheet format which presents each step in sequence has the effect of orienting the students towards the instructions. They spend their energy considering what is expected of them in each step which has the effect of focusing their attention on the professor’s requirements rather than on their own sense of what is conceptually sound.

Furthermore, the fact that students are graded on each step of the process makes them sensitive to the requirements for each step. Typically, they read the problem solving prompts thoroughly several times, and often return to them at the end to ask “did we miss anything?”. This indicates that they are treating the prompts as a direction or a recipe, and are framing their work during that prompt in terms of satisfying the grading requirements that it represents.

This attention to the steps as requirements that must be satisfied naturally leads them to approach problems algorithmically rather than what their activities mean conceptually. I believe that by having the steps printed and elaborated on the worksheet, we periodically remind and re-orient the students towards our grading requirements, which has the effect of encouraging a procedural rather than conceptual approach.

Finally, some research has shown that a strictly linear and forward-looking solution strategy may not be expert-like at all [84]. These results demonstrate the importance of using several strategies and switching flexibly between them. In order to enable our students to do this, a more flexible pedagogy may be required.

7.5 Methodological Contributions

Several results emerged from this dissertation that were not directly the result of investigations into the major research questions but were instead methodological comments or innovations that occurred as a part of those investigations. Several of these are listed below.
7.5.1 Interpretation of CLASS results

The interview study in chapter 4 revealed that students exhibit a wide diversity of perceptions of the nature of “physics reasoning skills” that are described in the CLASS survey question 30. The diversity of responses suggests that this CLASS question is not measuring the same thing for each student which is very important to consider when considering CLASS survey results.

Another troubling feature of this result is that students’ sense of the meaning of the phrase “reasoning skills used to understand physics” is often concerned with knowledge or practices that an expert physicist would not consider to be “reasoning skills”. For example, Samantha’s interpretation that these reasoning skills are primarily exam-taking strategies is likely not what the survey developers had in mind, and instead might represent precisely the kind of answer-making that physics teachers hope their students will eschew. In fact, only the “reasoning skills as problem solving” cluster of interpretations seems to match the intended meaning of this survey item. This, combined with the recognition of the diversity of students’ perceptions of what constitutes “everyday life” suggests that relatively few students responding to this survey item are responding in the sense that the survey developer’s intended.

This calls into question the survey’s developers statement that “the wording of each statement was carefully constructed and tested to be clear and concise and subject to only a single interpretation by both a broad population of students and a range of experts” [54].

Because my results do not show the same single interpretation, one might imagine that something about my population or interview protocol may be responsible for the difference. Without knowing more about the structure of the original interviews it is hard to guess what might be responsible for this discrepancy. Regardless my results suggest that it is not safe to assume that the CLASS statements are always interpreted in the same way by different students or that they are always interpreted in the way that an expert physicist might. This should offer caution to anyone working with and interpreting this survey.
7.5.2 Development of Coding Scheme for Real-World Connections

An important methodological contribution of this dissertation is the coding scheme for identifying students’ Real-World Connections during discourse. By operationalizing a Real-World Connection as the activation of resources that are rooted in a students’ experiences outside the classroom, I have defined RWC in a way that is consistent with the Resources and Framing theoretical framework. This way of examining students’ activation of resources in a classroom setting can be extended to other populations and other research questions.

7.5.3 Extension of Epistemological Framing Coding Scheme

In order to examine students’ epistemological framing during collaborative group problem-solving, I extended the behavior-based coding scheme developed by Scherr and Hammer in two ways. Firstly, by attending to the implicit goal of students’ discussion I demonstrated that the Discussion frame could be subdivided into two types of discussion: Procedural Discussion, where the implicit goal is to figure out what to do in order to make progress; and Conceptual Discussion, where the implicit goal is to figure out the meaning of the physics under consideration. The utility of making this distinction was illustrated by my subsequent analysis which showed that Conceptual Discussion was correlated with a significantly higher rate of Real-World Connections, indicating that students access their diverse resources differently in these different frames.

The second way I extended the Scherr and Hammer coding scheme was by demonstrating that their behavioral coding, which was originally done with video, could be done with audio recordings only. The high inter-rater reliability obtained by two coders working with different media (audio-only vs. audio+video) supports the notion that people use multiple semiotic means to communicate and coordinate their activities with each other.
7.6 Recommendations for Instruction

Based on the results of these studies, the following recommendations are provided for instructors that wish to promote real-world connections in their introductory physics course.

1. **Get to know your students.**

   The interview studies have shown that introductory students distinguish between relevance to themselves and relevance to others, and primarily make judgments of relevance based on their current lives and immediate career plans. The experience of the Physics 100 instructors demonstrates that it is not always easy to guess what settings your students will be familiar with.

   As such, using surveys or focus groups is a useful method for finding out more about your students. For example, you can investigate: Who are your students? What happens in their everyday lives? What are their career plans? What do they care about? The answers to these questions can be tremendously valuable in enabling an instructor to develop curriculum and associated pedagogies that are relevant to their students.

2. **Use everyday contexts in your teaching.**

   Not only will everyday contexts improve students’ perception of the relevance of physics to their real world, it will also enable them to make use of their everyday knowledge to interpret, solve, and make sense of problems. While this alone may not have a significant impact on students’ attitudes and beliefs about physics and its applications to everyday phenomena, it does offer them opportunities to identify with and participate in the course in ways that might not otherwise be available.

3. **Highlight real world consequences.**

   Introductory students perceive problems and circumstances that have clear consequences to be more relevant to the real world. My studies suggest that environmental and financial consequences are perceived as particularly relevant. If an understanding of a particular topic or problem is consequential in this way, it is important that this is made explicit to students.
4. Emphasize the importance of conceptual knowledge in problem solving, but don’t require adherence to a fixed strategy.

In this study, requiring students to perform each step of a structured problem-solving strategy was shown to be ineffective at promoting the use of conceptual knowledge. The requirement to adhere to a structured problem-solving strategy may inhibit the students’ conceptual framing and divert their attention to satisfying external requirements. However, this does not mean that structured problem-solving methods should be abandoned. Instead, teaching these methods with an emphasis on the importance and utility of conceptual consideration before and after calculation may be fruitful. To encourage students to develop a more sophisticated approach to problem solving, complex problem such as good context-rich problems should also be employed. However it is essential to ensure that the classroom culture as well as the assessment rubric emphasizes conceptual sensemaking as a part of problem solving.

5. Use a variety of problem types.

Students' unproductive epistemological belief that physics is “mostly calculations” may be reinforced by a physics course where the assessments are based only on calculations, even when those calculations are put into a real world context. Therefore, making extensive use of other types of problems to help students develop a more sophisticated picture of the nature of physics as well as some more sophisticated qualitative reasoning skills should be promoted.

By relaxing the requirements that problems be quantitative, tractable, and solvable in a short period of time students can be provided with instructional tasks that have a more authentic and genuine motivational imperative. For example, allowing more time for students to grapple with the complexities of an authentic real-world problem, making use of problems where students are encouraged to use qualitative reasoning, or using problems where students can interact, conduct experiments, and try things out rather than being required to come up with the “correct” solution in a single attempt are possible alternative strategies.
As well, in order for students to develop flexible expert-like problem-solving skills they need to learn several varieties of qualitative reasoning, such as choosing the relevant physics prior to calculation, estimation, and sensemaking strategies. These skills might be better developed via working on problems that emphasize qualitative reasoning, explanation, and sensemaking explicitly rather than having them attached to a quantitative calculation (as was the case in the context-rich problems in Physics 100).

6. **Attend to students’ epistemological framing.**

The correlation between Conceptual Discussion and students’ Real World Connections underscores the importance of paying attention to their epistemological framing and trying to create conditions that encourage Conceptual Discussion. While the best way to do this is a subject for future research, in the interim instructors might be well advised to avoid structuring student learning activities so that the correct procedure is obvious. Instead, offering activities that provide sufficient complexity so that students need to make use of their conceptual knowledge to understand the situation is preferable.

7.7 **Directions For Future Research**

There are several outstanding questions raised by this study of students’ framing and Real-World Connections during group problem-solving. I have listed a few of these below.

1. **Why are some student groups prone to make more RWC than others?**

As described in section 6.4.2.3 above, 6 of the 14 groups studied made the vast majority of the RWC in this study. While these groups engage in the same amount of Conceptual Discussion, the High RWC students make use of their real-world knowledge during Conceptual Discussion.

I conjecture that the High RWC students make more use of their own real-world knowledge during Conceptual Discussion because they assign a higher value of their own knowledge in a physics context. When they do engage in discussion to try to figure out what’s going on, they expect that the ideas that are constructed will be coherent with their knowledge of the real world. This is in contrast to students who may try to figure out
what’s going on but only hold what they perceive as sanctioned and official physics knowledge as being valuable in that conversation. I propose that, in a physics context, the High RWC students hold their own knowledge in higher esteem than the Low RWC students.

This suggests that the observed differences in these groups may be related to their self-concept of the relationship between themselves and science, an aspect of their identity and beliefs that have likely developed before arriving in our class. A fruitful avenue of research might be to make use of one of the existing scales of science identity to recruit low- and high-science-identity study participants, and then observe any differences in the rate of RWC during their problem solving.

Another possibility to explain this diversity in the number of RWC is simply that some students have more experience than others with the context of the particular problems that were a part of this study. Students with more familiarity with the particular contexts might have more relevant knowledge. However, given that the three problems studied here are set in relatively familiar contexts (e.g. driving a car) it seems unlikely that a group of four students wouldn’t have anybody in it with extensive familiarity with those contexts.

Another possibility is that social factors have a strong impact on the number of statements that students make in their discussion of a particular RWC. One of the student groups in this study consisted of four males who, at times, were engaged in a debate over physics assumptions that appeared to be a contest for social dominance of the group. The ongoing struggle between group members meant that they continued to discuss the same assumption for an extended period of time, inflating the count of RWC. This suggests that factors such as a student’s status within the group or their confidence in speaking in front of their peers might influence the number of RWC coded during group interaction. A review of the existing data with these social factors in mind would be able to reveal the interaction between a group’s social patterns and the RWC they produce.

2. How can we structure instructional materials to promote Conceptual Discussion?

The results of this study show that the structured problem-solving strategy studied in the Physics 100 recitations is not effective at promoting Conceptual Discussion at
appropriate times in the solution process and the recitations do not promote high levels of Conceptual Discussion overall. It seems likely that other instructional tasks might be more effective at promoting student Conceptual Discussion.

One candidate is Jeopardy Questions: problems where students are given the formula with all of the numbers filled in and are required to construct a physics problem that corresponds to that formula [47]. In a preliminary study of epistemological framing in problem solving, I found that students working on Jeopardy Questions made significantly more Real-World Connections and spent more time in the Conceptual Discussion frame than students working on context-rich questions. While these results were obtained with a preliminary version of the framing and RWC coding schemes, they do suggest that different tasks may be more effective than others for encouraging students to discuss the meaning of the physics under consideration.

I conjecture that we might find ways of encouraging students to engage in consideration of physical meaning by attending to their epistemic agency: the students’ feeling that they are responsible for judging the quality of the knowledge under consideration. I conjecture that tasks which are highly structured, evaluated by external people (such as the prof or TA), and are high stakes do not promote students’ epistemic agency: students frame these tasks in terms of the external requirements rather than in terms of what is sensible. However I believe that tasks which are more open-ended, evaluated by the students themselves, and/or are low stakes promote epistemic agency: the students feel more freedom to judge the quality of their work themselves. I propose that this feeling of being able to judge for oneself is what enables students to access a wider variety of conceptual resources and allows them to feel that it is sensible for them to be attempting to understand what is going on rather than simply “getting it done”. In future research I plan to explore the relationship between epistemic agency and conceptual framing and experiment with different instructional tasks that promote or inhibit epistemic agency.

3. Can the epistemological frame of Conceptual Discussion be used as a measure of student sensemaking?
Sensemaking is often described as a desirable activity for physics learners. The importance of sensemaking is highlighted whenever one witnesses the student working diligently and dogmatically through an erroneous calculation without ever considering its meaning or applications. The term sensemaking is used widely, but rarely defined. However, some researchers have attempted to operationalize it. For example Otero defines “the sensemaking mode” as including “discussions or utterances that were based on real or hypothetical experiences, peer instruction, and discussions or utterances about inconsistencies or unresolved issues” [85]. This is a very broad definition that includes, among other things, making sense of procedures, formulas, the professor’s expectations, and physics concepts.

Russ, Scherr, Hammer, and Mikeska developed a systematic coding scheme for analyzing student conversations for evidence that they are reasoning about physical mechanism [86]. This coding scheme identifies several different behaviors that indicate that mechanistic reasoning is occurring. The behavior that is the most strongly correlated with mechanistic reasoning is chaining, which involves making inferences between different properties of the system or between a system and an analogous system. Scherr and Hammer use the idea mechanistic reasoning in order to make arguments about sensemaking in their epistemological framing analysis [64]. They demonstrate that students who are mutually framing their activity as a discussion about ideas demonstrate the highest frequency of chaining compared to other frames, and conjecture that “this correlation reflects a consonance between students’ framing their activity as discussion and their reasoning about causal mechanisms”. Their implication that a particular epistemological frame is associated with reasoning about causal mechanisms supports my decision to operationalize sensemaking in terms of epistemological frames.

I propose that we define “sensemaking” as actively seeking conceptual connections in order to interpret new information in terms of what you already know. This may involve constructing analogies, restating ideas in new terms, or translating between different representations of the same idea so that one can construct a metaphor that maps a new concept onto the old concept. This type of conceptual metaphor allows one to reason about the new concept by making use of the entailments of the old concept [87]. By
interpreting new ideas and constructing robust conceptual metaphors that connect to what you already know, it enables reasoning with the new ideas and making sense of novel situations involving those new ideas.

As described in section 6.3.4, my framing coding scheme is a refinement of the one developed by Scherr and Hammer and my Conceptual Discussion frame and Procedural Discussion frame providing are largely subsets of their Green (discussion) frame. However I argue that only the Conceptual Discussion frame correlated with sensemaking behavior. I will illustrate this below with several examples of typical activities in the Procedural Discussion frame which do not involve the students making sense, and then discuss why I believe the Conceptual Discussion frame is a much better match for the notion of sensemaking.

One characteristic activity of my Procedural Discussion frame is discussing strategy for arriving at a solution. Students may go back and forth in conversation with each other several times in order to select the formula and assign values to the variables in the formula. While this behavior may be “making sense” in that it is determining an optimal course of action, it is rarely (or certainly not necessarily) “making sense” in the sense of connecting to and evaluating in terms of one's own existing knowledge.

Sensemaking requires that the students’ own knowledge come into play, something that we see infrequently in the Procedural Discussion frame. In the Procedural Discussion frame we mostly see students discussing strategy, attempting to interpret what the professor with the worksheet wants, or performing calculations, analyses, and evaluations based on what they have come to know as the standard physics.

By contrast, the Conceptual Discussion frame is where we see students striving to express, understand, and synthesize new ideas. Their focus is on figuring things out, in the sense that they are attempting to construct explanations of the ideas under consideration that meet their own expectations for valid knowledge. The activities of discussing physics concepts, translating mathematical or formal representations into informal or narrative representations, and interpreting the meaning of what is being said or discussed is an excellent description of “making sense.” It is for this reason that I propose to
operationalize the more general term “sensemaking” specifically as “engaging in Conceptual Discussion,” as defined by my epistemological framing coding scheme.

In future research I plan to clarify this definition of sensemaking and use detailed analysis of students’ discourse and behavior to argue that, for introductory physics students, the epistemological frame of Conceptual Discussion frame is an appropriate measure of student sensemaking.

4. Given that only the Assumptions prompt seems to promote Real-World Connections, is it worthwhile to continue to promote the use of a rigid problem-solving strategy?

Much of prior research on problem solving has focused on well-defined problems. My interest in problem solving has been more because I hope to enable students to develop flexible problem-solving skills that are useful to them on complex real world problems which may be ill-defined. By focusing on the students’ interaction with the problem-solving strategy during their group problem-solving, I have shown that such a strategy does not effectively promote students’ use of their conceptual knowledge during problem solving, but I cannot say whether such a strategy has benefits for long-term development of expert-like problem-solving skills.

Based on the success of the focus on Assumptions for encouraging Real-World Connections for some students, I advocate that instructors continue to focus on and require students to make and articulate assumptions as a part of problem solving. However, further research is required to determine what the value of requiring students to use a full multi-step method might be.

5. Does our use of a structured problem-solving method have anything to do with the students’ spontaneous use of their real-world knowledge during the Solve prompt?

One of the surprises of my research was that some students make use of their real-world knowledge to interpret and evaluate their results spontaneously as soon as those results are calculated. Since the Physics 100 pedagogy advocates and demonstrates a
structured problem-solving method that emphasizes making sense of your answers, it is plausible that these students’ behavior has been influenced by this method.

Another possibility is that it is students’ engagement with their real-world knowledge earlier in the problem-solving process that makes it more likely for them to evaluate their results in this way. A comparison of the nature of students’ spontaneous sensemaking across courses that use different (or no) problem-solving methods may help to identify whether these methods influence students’ spontaneous sensemaking.

6. How do students make use of physics in their everyday lives? According to Pugh, who researches how science learning can transform students’ perceptions of their world: “research is also lacking on the consequences that learning has on everyday experience. We simply have not looked carefully at the difference that learning is making or failing to make in the everyday, out-of-school experiences of our students” [8]. Pugh’s work, like my own, is motivated by a desire to influence students’ everyday lives, but is limited in scope to their actions within the classroom. In order to better investigate the ways in which learning science informs and affects students’ everyday lives, research methodologies that encompass students’ lives will need to be employed.
REFERENCES


[58] http://www.r-project.org/


237


Appendix A Physics 100 Tutorial Problems
Tutorials from 2007 (first year of course)

THE FOLLOWING WORKSHEET WAS USED FOR EVERY TUTORIAL PROBLEM IN 2007

UBC Introductory Physics Problem-Solving Worksheet

Not all these steps will be relevant for every problem, but if you skip a step you should write a couple of sentences to explain why.

1. Interpret the problem
   - visualize the events described in the problem
   - sketch a picture
   - identify your goal

Names of Group Members
2. **Model the Problem**
   - Identify the physical principles that are relevant to this situation
   - State any simplifying assumptions
   - Draw one or more physics models. These may include:
     - special diagrams (free-body diagram, energy bar chart, motion diagram etc.)
     - graphs of physics quantities
     - statements of limitations or constraints
     - a list of given information, including definitions of relevant symbols
3. **Plan a solution**
   - Translate the physics model into equations which represent the problem mathematically
   - Assess how you will solve these equations, and whether they will give a solution before going through the effort of actually solving them.

4. **Solve**
   - Insert the relevant quantities and solve for the answer
5. **Check Your Answer**
   - Check that the formula gives the correct units
   - Compare the answer to your existing experience
   - Check for reasonableness and completeness
Phys 100 Tutorial Problem #1

1. Drive carefully

A wealthy friend is always bragging about how he always speeds. He also likes to sound smart by using strange units. Once he shows up and starts telling everyone that he was going very fast on the drive to UBC from Burnaby… up to 25 m/s! Was he speeding?

2. It’s hard to hire good help these days

The contractor renovating your house has been staring at the same piece of paper for the last hour. You’re curious about what his problem might be (and well aware that you’re paying him by the hour!) so you decide to investigate.

He’s puzzling over the markings on a large stack of foam sheets that you recognize as wall insulation. He’s just received a shipment of six 4‘x8‘x4” sheets of it, but he can’t seem to figure out whether it meets the building code specifications or not! Sighing, you curse yourself for hiring the cheapest contractor you could find and start looking at his notes.

Each foam sheets is clearly stamped with its thermal resistance or “R-value” of 4, and the contractor tries to explain what that means:

“See, I know that the inverse of the R-value tells you the BTUs of heat that will leak out of each square foot of wall every hour. And I think that’s for each degree Fahrenheit of difference between the inside and the outside. So R-4 means if you have a temperature difference of 8 °F then you’ll lose 2 BTU / hr through each square foot of panel. The problem is that the government specifications are written in Metric!”

He shows you a printed sheet that reads:

Wall insulation in residential homes shall be rated with a thermal resistance of not less than 0.8 °K * m^2 / W

Do these sheets meet the minimum requirements?
Your friend is an artist who will shortly be unveiling his new work: a kinetic sculpture called "destruction." The sculpture is simple and has high impact. A 200-kg steel block is hung from the ceiling at the end of an 8-foot long rope. Steel has a density of 7800 kg / m$^3$. Another rope is attached to the block so that it pulls it horizontally. The other end of the horizontal rope is attached to a motor which is cleverly mounted with a movable pulley so that the rope always pulls the block horizontally with a constant force.

The block starts from rest when it is hanging straight down and moves very slowly until it is hanging at an angle of 30° to the vertical. At that point the horizontal rope will be released and the block swings until it crashes into a wall.

The motor for the sculpture will be powered by a battery with a limited energy capacity. He has asked you to help him figure out how much energy it will take to raise the block into position, to make sure the sculpture will work once it is unveiled. You make a test and determine that the maximum force exerted by the motor will be exactly enough to hold the block when it is hanging from the other rope at 30° from the vertical.

How much energy does the battery have to supply?

What assumptions do you need to make about the apparatus in order to figure this out?
A friend of yours has decided that he wants to be able to look into the fridge without opening the door, so he’s decided to install a glass door on his fridge. Because of your knowledge of physics he asks you to help him figure out whether this is a good idea.

The new door that your friend has rounded up is a single pane of glass 35 mm thick that used to be a part of a huge window. He is quite confident that he can install the hinges, handle, and seal on the door, but is worried about whether his food will still be kept cold.

The two of you look over his fridge and make some measurements. The fridge door is 42” tall by 26” wide. The existing fridge door has foam insulation about 2 inches thick. The fridge’s manual tells you that the internal volume is 20 cubic feet, and the inside temperature of the fridge is maintained at 3°C.

The fridge’s motor typically consumes 400 Watts of power to maintain its normal temperature, and it has a maximum rating of 800 W. The motor is about 50% efficient, which means that if the motor is consuming 400 W of electric power it will extract heat at a rate of 200 W from the fridge compartment. (The rest goes into heating up the motor and its surroundings, which is why they always put the motor on the outside of the fridge.)

You estimate that the interior of the fridge is usually filled about half with air and half with food. You know that air has a density of 1 kg / m³, and you guess that most food has a density pretty close to water: 1000 kg / m³.

To help with your calculations you look up some information on the internet. The thermal conductivity of glass is 1.1 W/m*K and its density is 2400 kg / m³. The thermal conductivity of most fridge insulation is around 0.03 W/m*K and its density is about 700 kg / m³.

How much extra power would need to be removed from the fridge to keep the same temperature?

Will the fridge be able to maintain the same temperature?
You are traveling in Australia and seeing as the weather is brilliantly sunny without a cloud in the sky you decide to head to the beach to get a tan. As you’re heading out the door the receptionist at your hotel reminds you that due to the hole in the ozone layer over Australia the solar radiation is very intense and can increase your risk of skin cancer. She gives you a pamphlet that tells people to avoid sun exposure when the “UV index” is higher than 6.

In tiny print on the bottom of the pamphlet it explains that the UV index is a measurement of the total intensity of radiation that you receive that has a wavelength between 200 and 300 nm. The UV index is a linear scale, which means that UV index of 2 has twice as much intensity as UV index 1. A UV index of 1 corresponds to an intensity of 2.5 W / m² of radiation within the 200 – 300 nm range.

The receptionist doesn’t know what the UV index is at the moment, but seeing as you are familiar with the physics of radiation, and you know that the surface temperature of the sun is around 5780 °K you think you can figure out the UV index on your own. You quickly look up a chart of the radiation spectrum of the sun. This chart includes some atmospheric effects, and gives a reasonable approximation of the solar spectrum as seen from the earth’s surface. (see the charts on the next page).

Assuming that you’d be lying face–down horizontally on the ground (and you’re too cheap to buy sunscreen), what would be the UV index of the radiation on your back at high noon?

Where in the sky (i.e. what angle) would the sun need to be in order for it to be safe for you to lay down and tan?
Phys100 Tutorial Problem 5

You are an astronaut for the Canadian Space Agency, on a mission to investigate the sun. When you are partway through your journey there is a problem with the spacecraft that means you have to step outside. Because the CSA is really cheap, the spacesuit they gave you is made of recycled black garbage bags and doesn’t have any thermal insulation, so the external temperature of the suit is the same as its internal temperature.

Before stepping outside you estimate that your total surface area is 1.8 m$^2$, and when you look in the mirror the area of your image is about 0.7 m$^2$. (Do you remember from Mastering Physics the amount of heat energy a typical human radiates?)

At what distance from the sun will it be for it to be safe to step outside in your spacesuit?

Describe how the temperature in your suit would change if you were working in a position such that the sun was directly over your head.

Bonus: How could you change the physical properties of the spacesuit to make it better?
The Greenhouse Effect

Inspired by the beauty of tropical orchids you have decided to take up gardening. You’re working on building a greenhouse to house them and keep them at their preferred growing temperature. The greenhouse is a box 2.5 m tall, 3 m wide, and 4 m long made of a single layer of glass. The glass house is built upon a slab of concrete which is painted white, so overall it reflects about 65% of the visible radiation incident on it. So far you only have two orchids, which will be planted in small boxes and set upon the concrete slab to keep their roots warm.

You want to figure out what temperature the concrete slab will be. Assume that the sun is directly overhead, and glass is treated such that it allows all the solar radiation through but absorbs all infrared radiation.

Hint: Which energy balance model do you think would be most appropriate for calculating the effect of the greenhouse?
Phys 100 Tutorial Problem 7

You have landed a summer job as the technical assistant to the director of an adventure movie shot here in Vancouver. The script calls for the Heroic cop to apprehend the fleeing criminals by jumping onto their car. The stunt will be conducted at the Mission Raceway drag racing course, which has a straight section 1.2 km long. You must determine whether this course is long enough to complete the sequence. The director is paying $20,000 per hour for the camera helicopter, so he wants to do this successfully in one take.

In the script, the Badguy comes around a corner onto the straight stretch at 95 km/hour, and passes a concealed police car where the Hero is waiting. Three seconds after the Badguy passes the police car, the Hero pulls onto the highway and accelerates at a constant rate of 2 m/s².
Phys 100 Tutorial Problem 8

Warmup Question: This question is meant to give you a chance to practice some of the concepts and calculations that will be relevant to the main question below. You can work on it individually or in groups, but don’t spend more than 10 minutes on it. If you don’t understand how to get started be sure to ask your TA for help right away.

A block of mass $m$ is held against a wall with a horizontal force $F$. The coefficient of static friction between the block and the wall is $\mu_s = 0.6$. What is the minimum force required to hold the block without slipping?

Main Question:
Because of your physics background, you have been able to get a job with a company devising stunts for an upcoming adventure movie being shot in Vancouver. In the script, the hero has been fighting the villain on the top of the locomotive of a train going down a straight horizontal track at 30 km / h. He has just snuck on the train as it passed over a lake so he is wearing his rubber wet suit.

During the fight, the hero slips and hangs by his fingers on the top edge of the front of the locomotive, which is a smooth vertical wall of steel. The villain, seeing his chance to kill the hero stomps on the hero's fingers so he will be forced to let go and slip down the front of the locomotive and be crushed under its wheels.

Meanwhile, the hero's partner is at the controls of the locomotive trying to stop the train. However she discovers that the brakes have been locked by the villain. She starts working on opening the lock, but it looks like it will take her at least 10 seconds to get it open. To her horror, she sees the hero's fingers give way before she can get the lock off. Since she is the brains of the outfit, she immediately opens the throttle causing the train to accelerate forward. This causes the hero to stay on the front face of the locomotive without slipping down giving her time to find another way to save the hero's life.

The movie company wants to know what minimum acceleration is necessary to perform this stunt. The hero weighs 80 kg in his wet suit. The locomotive weighs 100 tons. You look in a book giving the properties of materials and find that the coefficient of kinetic friction for rubber on steel is 0.50 and its coefficient of static friction is 0.60.
You have just finished buying an awesome birthday present for your friend Bill (a porcelain figurine of Captain Kirk) and are headed home on the bus. It’s a typical rainy Vancouver day and your bus driver must be late, because he is driving pretty fast. At one stoplight, he slams on the brakes and even locks up the wheels! The bus, which was traveling along at 65 km/h, skids to a stop in 42 meters. You are sitting right in the back of the bus, and were completely surprised by the sudden stop, so you don’t have time to grab Bill’s present, which is inside a box sitting on the seat next to you. Will the box slide off the seat?

Assume the mass of the bus is 10,000 kg and $\mu_s$ for rubber on wet roads is 0.5 and $\mu_k$ is 0.4. The $\mu_s$ between the box and the vinyl seat is 0.35, and $\mu_k$ is 0.25.
Phys 100 Tutorial Problem 10

**Warmup Question:** Calculate the current through the circuit and the power dissipated in each resistor in the circuit below.

![Diagram of a circuit with two resistors and a voltage source](image_url)

- $R_1 = 5 \, \Omega$
- $R_2 = 12 \, \Omega$
- $V_0 = 110 \, V$

**Main Question:**

You have built a cabin in the woods that is set back 600m from the nearest power line. The power company doesn't want to run extra wires out to your house, so to supply electricity to the cabin you’ve buried a pair of 6 gauge ($\frac{1}{6}$th of an inch in diameter) copper cables in the ground, which have a resistance of $0.6 \, \text{ohms / 1000 ft of length}$. The meter for your electricity is at the nearest power line.

When you have your dishwasher, washing machine, dryer, microwave, and stereo on your cabin is draws a total of 35A of current. In this case, how much power is being dissipated in the copper cables connecting to your house?

**Bonus:** What % of the total power going to your cabin is dissipated in these cables?
Physics 100 Tutorials from 2009.
Tutorial 1A – Personal Context

Physics 100 – Introduction to the Tutorials

**Format** – To help you progressively develop complex problem solving skills, the tutorials will start with smaller practice problems designed to develop particular skills. We will proceed to more complex problems by the end of the term.

**Group Work** – You will be working in groups of 3 or 4 which will be assigned by your TA. Your success will depend on your teammates and vice versa, and everyone will get the same grade for each tutorial. We’ll be talking about ways to make sure your group communicates well and everybody gets a chance to contribute equally.

**Goal** – The tutorials are the main place for you to practice USING physics. One of the key course goals for Physics 100 is that you’ll learn to apply problem solving techniques to address real world problems in terms of physics concepts. We’re hoping you’ll learn some technical problem solving skills that can help you to make decisions throughout your life. This will include learning how and when to make approximations to simplify complex situations.

**Student Research Project**

A significant portion of your grade is based on your Group Research Project: you will interpret and solve a real world question or problem using physics. You will then create a poster to present your solution to your peers at the end of term.

For example, one of our project topics has been to investigate the effect of the suggestion to “Eat local food” on energy consumption and greenhouse gas emissions. It will be up to you to determine what “local” means, how that is different from the type of food that people normally eat, how to perform calculations to compare the two types of food, and how to present the results of your calculations in a way that is meaningful to your audience.

One important purpose of the tutorials is to help you to develop the skills you’ll need in order to do this type of modeling and comparison.

**Problem Solving Strategy for Complex Problems**

To help you learn to solve more complex problems, we’ll be using a problem solving process that can be used on a wide variety of problems including your final research project. We’ll introduce the procedure here, and explore each of these steps in detail at a later date.

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<td>IV) Solve the Problem</td>
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<td>V) Error Checking and Sensemaking</td>
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Example Problems

1. Interpret the Problem (Step I: Identifying Goals): Read the problem below and then answer the question in **bold** below. You do NOT need to solve this problem.

You are moving to a new house about 80 km away and need to rent a truck. You have the choice of renting a smaller truck for $65 that burns 7.7 liters / 100 km and has a maximum payload of 750 kg or a larger truck for $85 that burns 9.7 liters / 100 km and has a payload of 1,300 kg. You estimate that you have about 1000 kg of stuff to move, and need to decide which truck to rent

**In order to compare between the two trucks what is the final quantity that you should calculate?**

2. Create a Physics Model (Step III: defining Assumptions)

You are helping your uncle to fix his roof. In order to get the roofing supplies up on top of his two storey house you had planned to set up a pulley with a rope hanging from both sides. That way, one person working on the ground can hook a bundle of supplies onto one end and then pull down on the other end of the rope to pull the bundle up to the person on the roof. Your uncle has a 30 foot rope with a hook on one end.

**In order to determine if this rope is long enough for your plan you might need to make some assumptions about particular quantities relevant to the problem. What values would you need to assume?**

Which of these assumptions is the most critical to answering this problem? Describe one circumstance where your assumption would be incorrect.
3. Checking Your Answer (Step V: Error Checking and Sensemaking)

The result of one of your calculations shows that the total population of Vancouver consumes $1 \times 10^9$ kg of food every year. Perform a simple calculation to examine the reasonableness of this answer.

**New Problem Type: Jeopardy Questions**

A jeopardy question starts closer to the end of a physics problem with an equation or set of equations that describe a physical system or process. Your job will be to come up with a model or a description that fits those equations. These types of questions help to develop your ability to Identify Relevant Physics and Create a Physics Model. Note there may be MANY correct answers to these types of questions.

**Example Jeopardy Question:** The equations below describe an object undergoing some process. Solve for the unknowns, then construct a diagram depicting the process and explain a physical situation that could correspond to this process.

Equations: 
\[ (320 \text{ kg}) \times (9.8 \text{ m/s}^2) \times (12 \text{ m}) = \frac{1}{2} \times (320 \text{ kg}) \times v^2 \]

**Example Solution:** 
\[ v = 7.67 \text{ m/s}^2 \]

This equation shows a balance between potential and kinetic energy. It describes a roller coaster car with a mass of 60 kg carrying four passengers weighing 70 kg each starting from rest at the top of the lift hill, and then moving down the track so that it loses 12 meters in elevation. Its speed at the bottom of
4. Jeopardy Question (Step II: Identifying Relevant Physics and Step III: Modeling)

The equations below describe an object undergoing some process (different from the one above). Solve for the unknowns, then construct a diagram depicting the process and explain a physical situation that could correspond to this process.

**Equation:**

\[
\frac{1}{2} \times 0.2 \text{ kg} \times (2.3 \text{ m/s})^2 + 0.2 \text{ kg} \times 9.8 \text{ m/s}^2 \times 15 \text{ m} = \frac{1}{2} \times 0.2 \text{ kg} \times (0.6 \text{ m/s})^2 + 0.2 \text{ kg} \times 9.8 \text{ m/s}^2 \times h
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Tutorial 1B – Real Context
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Example Problems

1. Interpret the Problem (Step I: Identifying Goals): Read the problem below and then answer the question in **bold** below. You do NOT need to solve this problem.

   A landscaping contractor needs to purchase a new vehicle to run his business. He is considering the purchase of an $18,000 truck that burns 7.7 liters / 100 km and has a maximum payload of 750 kg or a $29,000 truck that burns 9.7 liters / 100 km and has a payload of 1,300 kg. He usually works on one job in Vancouver each week, and estimates that he needs to haul around 800 kg of rock, sand, and other materials from a gravel pit in North Vancouver to each job. He expects each truck to last him five years,

   **What is the final quantity that he should calculate in order to compare between the two trucks?**

2. Create a Physics Model (Step III: defining Assumptions)

   The landscaping contractor from problem 1 is working to fix a roof. In order to get the roofing supplies up on top of his two storey house he had planned to set up a pulley with a rope hanging from both sides. That way, one person working on the ground can hook a bundle of supplies onto one end and then pull down on the other end of the rope to pull the bundle up to the person on the roof. He has a 30 foot rope with a hook on one end, and wants to figure out if this will be long enough.

   **In order to determine if this rope is long enough for his plan he might need to make some assumptions about particular quantities relevant to the problem. What values would he need to assume?**

   Which of these assumptions is the most critical to answering this problem? Describe one circumstance where his assumption would be incorrect.
3. Checking Your Answer (Step V: Error Checking and Sensemaking)

The result of one of your calculations shows that the total population of British Columbia consumes \(80 \times 10^9\) kg of food every year. Perform a simple calculation to examine the reasonableness of this answer.

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This equation shows a balance between potential and kinetic energy. It describes a mine cart with a mass of 320 kg starting from rest at the top of a track, and then moving down the track so that it loses 12 meters in elevation. Its speed at the bottom of the track will be given by \(v\).
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Today we will be creating predictive scientific models and looking at their capabilities. That sounds fancy but it is something you already do.

**Part I: a familiar example – a Budget. (15 minutes)**

1. Working with your group, create a monthly budget for a typical student in your group. Include any details you think would be part of a reasonable model.

2. Assume you get a $5000 student loan on September 1. Use your model to predict how much money you will have at the end of November.
3. How likely is it that your prediction above will be exactly correct?

4. If your prediction would not be exactly correct, how does that impact the usefulness of this model?

5. Can this model be used to predict exactly how much money you will have on November 18th at 3 p.m.? If yes, explain how. If not, explain why not.

6. If this is NOT possible, how does that impact the usefulness of this model?
Imagine you live at the University Residences and need to run errands to the Grocery store, a shoe store, and the motor vehicle licensing office. You need to complete your errands in the shortest possible time and then meet up with a study partner to get some notes from them.

**What is the shortest time it will take you to run your errands and return Home?**

As you work out an answer to this question, pay attention to any simplifications or assumptions you need to make. Be sure to write these down, as well as all other information that’s relevant in your calculation. **Don’t spend more than 10 minutes working on this.**
DISCUSSION part III - Connecting to Physics Models (5 minutes)

Physics models are just like the ones you have been working with, but we need a few more details in order to make sure they are clear. In particular, your physics model needs to contain all the information we need to make the translation to mathematics. (i.e. define your symbols and directions) A physics model may also include additional specialized diagrams that make certain calculations easier.

A complete model may include

- A statement of known and unknown quantities, with appropriate symbols defined
- A specific physics diagram (free-body diagram, energy bar chart, motion diagram etc.)
- A coordinate system that specifies the reference and direction of measurement for any spatial variables. (e.g. “x = 0 is the tabletop, positive x is down” or equivalent symbols)
- Relationships between the physical variables (e.g. \(a_1 = a_2\))
- Simplifying assumptions (i.e. friction negligible, massless rope, constant acceleration etc.)
- Initial conditions (i.e. \(V_i = 0, a_i = -g\))

INDIVIDUAL HANDOUTS

Take-home: Properties of Models

In this tutorial, we’ve discussed the properties of two models. The table on the next page summarizes how these models can be described in terms of those properties. For your homework, look at the model in Example #3 below, and explain how the properties of models are represented in that example

Example #1: A monthly budget
A budget is just a list of income and expenses that is used to estimate a person’s monthly cashflow.

Example #2: A model of driving in Vancouver.
This model is based around a map, but ALSO includes assumptions that let us guess at average speed. These additional assumptions are necessary in order to use this model to estimate times.

Example #3: A model used to calculate energy requirements of a cyclist

Problem: You are riding your bicycle up the hill on 16th avenue near Dunbar. How many calories do you burn to propel yourself up the hill?

The hill is about 600 meters long and it has an average grade of 7% (which means it rises 7 meters for every 100 meters of road).

Model:
\( \text{h} = 0 \) is the bottom of the hill

\text{Assume} \ V_i = V_f \approx 10 \text{ km/h}

\text{At this speed, neglect air resistance}

\( h = 600 \times 7\% \)

\( = 42 \text{ m} \)

\text{Neglect rolling friction}

\( M_{\text{tot}} = M_{\text{bike}} + M_{\text{pupil}} \)

\( = 15 \text{ kg} + 70 \text{ kg} \)

\( = 85 \text{ kg} \)

\text{Assume same mass throughout}
Explain how the properties of models are represented in the model used for the bus problem

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<tr>
<th>Model Property</th>
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<td></td>
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Example #3: A model used to calculate energy requirements of a bus

Problem: What is the minimum horsepower a bus engine needs in order to propel a bus full of people up the big hill on 16th avenue at a reasonable speed?

The maximum rate of energy output of an engine is called its Power, and it’s often measured in units called horsepower. One horsepower is equivalent to 750 Joules of energy output each second. The hill is about 600 meters long and it has an average grade of 7% (which means it rises 7 meters for every 100 meters of road. A typical city
bus has a mass of 8500 kg and can carry a load of 70 passengers.

Model:

\[
\begin{align*}
\text{Assume } V_i & > V_f \\
\text{At this speed, } & \approx 50 \text{ km/h} \\
\text{Assume difference in fuel weight is negligible}
\end{align*}
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Goal – by the end of this tutorial you will be able to
• Identify clear quantitative goals for real-world problems
• Identify irrelevant information for real-world problems
• Perform simple calculations of heat-loss by conduction.

One of the main differences between doing physics in the textbook and doing physics in the real world is that in the real world it is up to YOU to decide which calculations to do and which information to use in your calculations. Today we’re going to practice these skills with a few problems you might encounter in the real world. To help you out, we’ll let you know that ALL of the problems today will have to do with heat transfer by conduction. The main formula for heat transfer by conduction is:

\[ \frac{Q}{t} = k A \frac{\Delta T}{d} \]

You may also need to know the thermal conductivity of common materials. A brief table is given below:

<table>
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</tr>
<tr>
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**Question 1:** You live in a house that is pretty old and doesn’t have double-paned windows. Your heating bill in the winter is really big, and you think it might be due to the huge single-paned window in the living room. Your landlord has told you that he is willing to replace it with a double paned window but he would need to raise the rent. You want to do a quick calculation to see if it will be worth it to get him to do this. If electricity costs 1.6 cents/ MJ, how much money does it cost you to replace the heat lost out the single-paned window each day in the winter?

The window is 130 cm wide, 75 cm tall, and 4 mm thick. Assume the temperature on the inside surface of the window is 19 °C and the outside surface temperature is 4 °C. The room is heated by an electric heater with a maximum capacity of 1500 W.

**Interpret the problem:** write a short summary of what you think the problem is asking. Clearly identify the GOAL of this problem. i.e. what comparison or calculation will you need to make in order to answer this question.

**Model:** Which of the information given is needed to achieve your goal? Which of the given information is NOT relevant to achieving your goal?
Solve the problem.

...

Question 2: (note you do NOT need to solve this problem completely. Read it and look at the questions in bold underneath)

To help your application to med school you take a summer job doing biology research in the Antarctic. You will gain valuable dissection experience working with a team that will be studying the winter metabolism of Emperor Penguins and their chicks.

As your team is prepping to head down to Antarctica, your manager asks you to buy snow suits for the entire team. These are thick jackets and pants that cover the torso, arms, legs, and head of the wearer, and will hopefully keep the wearer warm. There isn’t much gear that will protect you in the harshest of Antarctic blizzards, but he asks you to make sure that the snow suits are good enough to keep the team at a comfortable 20 °C on the ‘warm’ days where the outside temperature is around -50 °C.

The suits that he’s suggested have 4 inches of duck down insulation, which has a density of 2.84 kg/m³. You know that a typical human being weighs about 70 kg, is 5’6” tall, and emits about 100W of heat over their entire body which has a surface area of around 1.7 m². Will these snow suits work?

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Model: Which of the information given is needed to achieve your goal? Which of the given information is NOT relevant to achieving your goal?
Follow-up Questions:

What do you need to know about a problem before you can determine which information is needed or relevant?

What are the features of these problems that might suggest that thermal conduction is the most important physics here?
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</table>
Question 1: You are working as a consultant, and doing an energy audit for a client to help her cut down her heating bills. She has bought a house that is pretty old and doesn’t have double-paned windows. She is thinking about buying a new window for their living room to cut down on heat losses. If electricity costs 1.6 cents/ MJ, how much money does it cost her to replace the heat lost out this single-paned window each day in the winter?

The window is 130 cm wide, 75 cm tall, and 4 mm thick. Assume the temperature on the inside surface of the window is 19 °C and the outside surface temperature is 4 °C. The room is heated by an electric heater with a maximum capacity of 1500 W.

Interpret the problem: write a short summary of what you think the problem is asking. Clearly identify the GOAL of this problem. i.e. what comparison or calculation will you need to make in order to answer this question.

Which of the information given is needed to achieve your goal? Which of the given information is NOT relevant to achieving your goal?

Solve the problem.
A friend of yours has gotten a job doing biology research in the Antarctic.

He is preparing to head down to do some work, and asks you for some help to pick out a snow suit. These are thick jackets and pants that cover the torso, arms, legs, and head of the wearer, and will hopefully keep the wearer warm. There isn’t much gear that will protect you in the harshest of Antarctic blizzards, but he asks you to help him pick a snow suit that will be good enough to keep him at a comfortable 20 °C on the ‘warm’ days where the outside temperature is around -50 °C.

One suit he’s looking at has 4 inches of duck down insulation, which has a density of 2.84 kg/m³. Your friend weighs about 70 kg and is 5’6” tall, and you know that a typical person emits about 100W of heat over their entire body, and has a surface area of around 1.7 m². Will this snow suit work?

Interpret the problem: write a short summary of what you think the problem is asking. Clearly identify the GOAL of this problem. i.e. what comparison or calculation will you need to make in order to answer this question.

Model: Which of the information given is needed to achieve your goal? Which of the given information is NOT relevant to achieving your goal?
Follow-up Questions:

What do you need to know about a problem before you can determine which information is needed or relevant?

What are the features of these problems that might suggest that thermal conduction is the most important physics here?
Tutorial 4A – Personal Context
Phys 100 Tutorial 4 – Identifying Relevant Physics

Topic – heat loss by radiation
Goal – identifying relevant physics
In order to plan your attack on a particular problem, you need to make decisions about which physics is most relevant to that problem. In some cases we may choose to neglect a particular physical mechanism because we believe that it won’t change the answer very much.
Here is a rough guide to help determine whether conduction or radiation is relevant to a particular problem.

<table>
<thead>
<tr>
<th>Student Name</th>
<th>Role</th>
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<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

Is the object in contact with other

yes

Does the contacted matter have very low* thermal

no

yes

Does the contacted matter allow passage of infrared radiation?

no

yes

Radiative heat transfer

OUT: Blackbody radiation of energy out entire surface area
IN: if there is directed radiation, absorption of directed radiation over x-sectional area
AND/OR If there is no directed radiation, absorption of ambient radiation over entire surface

Conductive Heat Transfer

IN OR OUT depending on whether body is warmer or cooler than surrounding matter.

*keep in mind that “very low thermal conductivity” depends on the context. If the material in question is the ONLY path for thermal conduction and the ONLY path for heat transfer, then it would be unwise to neglect conductive heat transfer.
For each of the situations below, identify whether each of the following physical effects are important to consider in a calculation (i.e. non-negligible). Briefly explain why or why not. You do NOT have to solve the problem.

I. Heat transfer via conduction \( P = k A \Delta T / d \)
II. Heat emitted via radiation \( P = e A T_{\text{object}}^4 \)
III. Heat absorbed from directed radiation \( P = I_0 A \cos \theta \)
IV. Heat absorbed from ambient radiation \( P = e A T_{\text{ambient}}^4 \)

**Example:** Heat transfer through a refrigerator door. For fixed power of refrigeration motor and room temperature, find the temperature of the food inside.

*Only mechanism I is relevant. There is no radiation that passes through the refrigerator door so II, III, and IV cannot affect the heat transfer.*

**Situation A:** You are thinking about replacing the single-paned window in your living room but aren’t sure if it will be worth the expense. Assuming a fixed interior temperature, find the net heat transfer through the window each second.

**Situation B:** You are sunbathing in your swimsuit near a pool and you start to become overheated. It’s not at all windy, but you’re still concerned that it will be too cold in the shade. You want to estimate what your equilibrium skin temperature will be if you are standing in the shade.
Situation C: You have a job as a biology intern for the summer studying the diet of wild seals. You need to estimate the amount of calories a seal burns overnight when it sleeps in the water. Assuming a constant body temperature, find the average heat loss per second of the seal.

Now that we have a sense of which methods of heat transfer are important, let's think about which ones are dominant. For situation A above RANK the importance of the heat transfer mechanisms I – IV and give reasons for your ranking. (NB: in order to answer this you will have to model the window and make some reasonable assumptions)

Imagine you want to decrease the heat lost through your living room window, and you have a choice between applying a special coating reduces the infrared radiation transfer through the window by 50%, OR purchasing a double-paned window which reduces the conductive heat transfer by 90%. Which of these would be more effective? Why?
Topic – heat loss by radiation
Goal – identifying relevant physics
In order to plan your attack on a particular problem, you need to make decisions about which physics is most relevant to that problem. In some cases we may choose to neglect a particular physical mechanism because we believe that it won’t change the answer very much.
Here is a rough guide to help determine whether conduction or radiation is relevant to a particular problem.

### Radiative heat transfer

**OUT:** Blackbody radiation of energy out entire surface area
**IN:** if there is directed radiation, absorption of directed radiation over x-sectional area
AND/OR If there is no directed radiation, absorption of ambient radiation over entire surface

### Conductive heat transfer

IN OR OUT depending on whether body is warmer or cooler than surrounding matter.

*keep in mind that “very low thermal conductivity” depends on the context. If the material in question is the ONLY path for thermal conduction and the ONLY path for heat transfer, then it would be unwise to neglect conductive heat transfer.*
For each of the situations below, identify whether each of the following physical effects are important to consider in a calculation (i.e. non-negligible). Briefly explain why or why not. You do NOT have to solve the problem.

I. Heat transfer via conduction \( P = k A \Delta T / d \)
II. Heat emitted via radiation \( P = e A T_{\text{object}}^4 \)
III. Heat absorbed from directed radiation \( P = l_0 A \cos \theta \)
IV. Heat absorbed from ambient radiation \( P = e A T_{\text{ambient}}^4 \)

Example: Heat transfer through a refrigerator door. For fixed power of refrigeration motor and room temperature, find the temperature of the food inside.

Only mechanism I is relevant. There is no radiation that passes through the refrigerator door so II, III, and IV cannot affect the heat transfer.

Situation A: Because of your excellent organizational skills and physics background your employer has given you the job of coordinating with the contractor that is constructing an addition for your building. You want to figure out what kind of windows to buy for the new lobby. Assuming a fixed interior temperature, find the net heat transfer through the lobby windows each second.

Situation B: You are contracted to design an experiment that will be conducted in orbit on a small satellite which has a reactor that provides a fixed amount of heating power. To determine the minimum temperature your experiment will endure, find the equilibrium temperature of the satellite when it is in the earth’s shadow.
Situation D: Your friend is a biologist and is studying the diet of wild seals. She asks for your help on her research project. She needs to estimate the amount of calories a seal burns overnight when it sleeps in the water. Assuming a constant body temperature, find the average heat loss per second of the seal.

Now that we have a sense of which methods of heat transfer are important, lets think about which ones are dominant. For situation A above RANK the importance of the heat transfer mechanisms I – IV and give reasons for your ranking. (NB: in order to answer this you will have to model the window and make some reasonable assumptions)

Imagine you want to decrease the heat lost through the lobby windows, and you have a choice between applying a special coating reduces the infrared radiation transfer through the window by 50%, OR purchasing a double-paned window which reduces the conductive heat transfer by 90%. Which of these would be more effective?
Tutorial 5A – Personal Context

Phys 100 Tutorial 5

Today we will be working on what are possibly the most important skills in using physics – sensemaking and error checking. This is when we look at the results of our calculations and ask ourselves “Is this correct?” and “What does this mean?”. These skills are similar, in that often trying to make sense of your answer will help you to understand whether or not it is correct.

Today we will be working on your error checking and sensemaking with the following problem and solution. Read the Problem and Solution, and then answer the questions that follow. You do NOT need to solve this problem.

**Problem:** Something terrible has happened: during a kayaking trip a storm separated you from your group and guide, and you washed up on the beach all alone. You were able to build a fire to help keep warm, but after an entire day of waiting for rescue there’s no sign of a search party.

After looking at the lay of the land and figuring out directions from the stars, you have a decent idea that you’ve washed up about 15 km from the shipping lane in the main part of the channel. You remember your guide mentioning that it is used by fishing boats heading to Alaska, so you decide to try to build up your fire to attract the attention of one of those boats. There is a limited supply of firewood, so you don’t want to build it TOO large as the firewood will run out quicker.

You decide to use your physics knowledge to estimate how large the fire needs to be to be seen from 3 km away. From class you recall that people’s sensitivity to light depends on color and contrast, but that a perfectly dark-adapted eye can see a candle in a perfectly dark background from a distance of about 4 km. A quick calculation shows that this corresponds to an intensity of $8.3 \times 10^{-7}$ Watts/m$^2$.

Assuming the temperature of burning wood is around 450 $^\circ$C, how big would your fire need to be in order to be clearly visible from the shipping lane?
Solution:

Stefan-Boltzmann Law:

\[ P = \sigma e A T^4 \]

\[ \frac{P}{A} = \sigma T^4 \]

\[ = (5.67 \times 10^{-8}) \cdot (450)^4 \]

\[ = 2325 \]

Inverse Square Law:

\[ \frac{I_1}{r_1^2} = \frac{I_2}{r_2^2} \]

\[ r_1^2 = \frac{I_1 \cdot r_2^2}{I_2} \]

\[ = \frac{2325}{8.3 \times 10^{-7}} \cdot (15)^2 \]

\[ r_1^2 = 793896 \text{ m} \]

The fire needs to have a radius of \( 7.9 \times 10^5 \text{ m} \). This is impossible and we should find another way to get rescued.
Part I – Brainstorming: After we complete a calculation like this we want to try to interpret it. This interpretation usually falls into two categories: error checking and sense making. Basically we try to check the result in order to reassure ourselves that it is the correct result and that it makes sense.

It is always best if we can think of more than one way to check the result of our calculation. Brainstorm with your group - how many different ways can you think of to check the result of this calculation WITHOUT just re-doing the calculation from the beginning?

Now let’s try to think of more general ways that we could check the answer of any particular problem. Try to generalize each of the methods you developed above by describing it as a general strategy that could be useful for other physics problems.
**Part I Discussion.** There are many common strategies for sensemaking and error checking. A few of the common ones that are especially useful in Physics 100 are listed here:

1. **Compare the answer to a benchmark.** We call numbers that you already know from your everyday experience or from physics class benchmarks. Benchmarks aren’t exact numbers… they are just approximate to give you a rough idea of the order of magnitude of certain types of result.

   For example, you already know that cars drive at around 50 km/h (your benchmark), so if you get an answer that suggests a car is traveling at 400 km/h you know something is wrong. You should try to actively develop a list of benchmarks that you can use for checking answers.

<table>
<thead>
<tr>
<th>Useful Benchmarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of a car: ~50 km/h</td>
</tr>
<tr>
<td>Walking speed of a human: ~4 km/h</td>
</tr>
<tr>
<td>Pop’n of Vancouver Metro Area: ~ 2 million</td>
</tr>
<tr>
<td>Pop’n of BC: ~4.5 million</td>
</tr>
<tr>
<td>Pop’n of Canada: ~ 34 million</td>
</tr>
<tr>
<td>Power consumption of a lightbulb: ~ 100W</td>
</tr>
<tr>
<td>Food energy consumption of a human: ~100W</td>
</tr>
<tr>
<td>Thermal energy radiated by a human: ~800W</td>
</tr>
</tbody>
</table>

2. **Perform a simple calculation to bring the answer to a known scale.** For example, if you calculate that the total yearly energy consumption in B.C. is $10^{17}$ Joules, it would be hard to compare this to any benchmarks you know directly. However, if you use the total energy per year to calculate the energy per person per day, it might be easier to get a sense of whether this number is reasonable or not. To do this one I would probably end up comparing to the typical power consumption of a lightbulb, and calculate how many lightbulbs I would need to leave on all day.

3. **Perform an additional calculation using simpler physics.** Sometimes there is more than one way to solve a physics problem. If there is a simpler, but less accurate method for solving the current problem sometimes you can get a good check of your answer by doing that parallel calculation.

4. **Consider what happens under extreme conditions.** Basically we consider what might happen to our final answer if one of the initial values (also called parameters) were different. We ask ourselves questions like “If the mass was doubled, what would happen to the final answer?”.

   Often we only care about whether the result would increase or decrease as we vary a parameter. Understanding this relationship can be very helpful in comparing to what we already know. For example, if at the end of a long calculation we can see that a car burns less gasoline if the car gets heavier, that would NOT agree with our common sense and we would have good reason to doubt that result.
Part II: - Correction of the Example Solution. Explicitly list three major errors made in the solution above, and explain what should have been done differently.

Part III – (BONUS) Determine the correct solution to this problem. Don’t forget to include your model and assumptions.
Tutorial 5B – Real Context

Phys 100 Tutorial 5

Today we will be working on what are possibly the most important skills in using physics – sensemaking and error checking. This is when we look at the results of our calculations and ask ourselves “Is this correct?” and “What does this mean?”. These skills are similar, in that often trying to make sense of your answer will help you to understand whether or not it is correct.

Today we will be working on your error checking and sensemaking with the following problem and solution. Read the Problem and Solution, and then answer the questions that follow. You do NOT need to solve this problem.

Problem: You are working on a search-and-rescue team and are helping to plan a mission to find a hiker lost in the wilderness north of Vancouver. A rescue helicopter will be flying back and forth in parallel sweeps over the forest at 120 km/hr using an infrared camera (like the one demonstrated in class) to look for the lost hiker.

The infrared camera operates in the infrared wavelength range. You reason that the most likely source of infrared radiation they are going to see is the person’s head, because it is not covered by clothes. The camera needs a minimum of 5 W/m² of radiation to show a faint image of the person’s head. In order to plan the distance between the helicopter’s search sweeps, estimate the maximum distance from which the rescue helicopter can detect the person.
Solution:

Stefan-Boltzmann Law:

\[ P = \sigma A T^4 \]

\[ \frac{P}{A} = \bar{I} \]

\[ T_{\text{head}} = 30^\circ \]

\[ \bar{I} = 1 \]

\[ \frac{A}{A} = \sigma T^4 \]

\[ = (5.67 \times 10^{-8}) (30)^4 \]

\[ = 0.046 \]

Inverse Square Law:

\[ \frac{I_1}{I_2} = \frac{r_1^2}{r_2^2} \]

\[ r_2^2 = \frac{I_2}{I_1} \times r_1^2 \]

\[ = 5 \times 10^{-6} \times \left(\frac{12}{0.046}\right)^2 \]

\[ r_2 \approx 1.56 \times 10^{-2} \text{ m} \]

Assume \( r_{\text{head}} \approx 12 \text{ cm} \)

\( r_1 = \text{radius of head} (12 \text{ cm}) \)

\( r_2 = \text{radius of helicopter canopy} \approx (\text{unknown}) \)

This radius is much smaller than the distance to the helicopter. Therefore, the helicopter can see you.
**Part I – Brainstorming:** After we complete a calculation like this we want to try to interpret it. This interpretation usually falls into two categories: error checking and sense making. Basically we try to check the result in order to reassure ourselves that it is the correct result and that it makes sense.

It is always best if we can think of more than one way to check the result of our calculation. **Brainstorm with your group - how many different ways can you think of to check the result of this calculation WITHOUT just re-doing the calculation from the beginning?**

Now let’s try to think of more general ways that we could check the answer of any particular problem. **Try to generalize each of the methods you developed above by describing it as a general strategy that could be useful for other physics problems.**
Part I Discussion. There are many common strategies for sensemaking and error checking. A few of the common ones that are especially useful in Physics 100 are listed here:

5. **Compare the answer to a benchmark.** We call numbers that you know from your everyday experience or from physics class benchmarks. Benchmarks aren’t exact numbers… they are just approximate to give you a rough idea of the order of magnitude of certain types of result.

For example, you already know that cars drive at around 50km/h (your benchmark), so if you get an answer that suggests a car is traveling at 400 km/h you know something is wrong. You should try to actively develop a list of benchmarks that you can use for checking answers.

6. **Perform a simple calculation to bring the answer to a known scale.** For example, if you calculate that the total yearly energy consumption in B.C. is $10^{17}$ Joules, it would be hard to compare this to any benchmarks you know directly. However, if you use the total energy per year to calculate the energy per person per day, it might be easier to get a sense of whether this number is reasonable or not. To do this one I would probably end up comparing to the typical power consumption of a lightbulb, and calculate how many lightbulbs I would need to leave on all day.

7. **Perform an additional calculation using simpler physics.** Sometimes there is more than one way to solve a physics problem. If there is a simpler, but less accurate method for solving the current problem sometimes you can get a good check of your answer by doing that parallel calculation.

8. **Consider what happens under extreme conditions.** Basically we consider what might happen to our final answer if one of the initial values (also called parameters) were different. We ask ourselves questions like “If the mass was doubled, what would happen to the final answer?”.

   Often we only care about whether the result would increase or decrease as we vary a parameter. Understanding this relationship can be very helpful in comparing to what we already know. For example, if at the end of a long calculation we can see that a car burns less gasoline if the car gets heavier, that would NOT agree with our common sense and we would have good reason to doubt that result.
Part II: - Correction of the Example Solution. Explicitly list three major errors made in the solution above, and explain what should have been done differently.

Part III – (BONUS) Determine the correct solution to this problem. Don’t forget to include your model and assumptions.
Tutorial 6A – Personal Context

Phys 100 Tutorial 6

Today’s tutorial will use Jeopardy Questions to work on your ability to visualize and construct physics models. A Jeopardy Question is a question where you start with the equations and work backwards to construct the question that the equation is relevant to.

Example Jeopardy Question: The equations below describe an object undergoing some process. Solve for the unknowns, then construct a diagram depicting the process and explain a physical situation that could correspond to this description. Where necessary, provide a diagram of motion or energy flows.

\[ 5.67 \times 10^{-8} \text{ W/(m}^2 \text{ K}^4) * 0.8 * (1.7 \text{ m}^2) * (303 \text{ K})^4 \times \text{ Cal/hr} * 4.18 \text{ kJ/Cal} * 1\text{ hr/3600s} + 5.67 \times 10^{-8} \text{ W/(m}^2 \text{ K}^4)*0.8*(1.7 \text{ m}^2)*(293 \text{ K})^4 = \]

Example Solution: This equation represents a radiative energy balance with an extra power term on the right hand side. The power is expressed in Calories because it is coming from biological metabolism. The other terms represent emitted and absorbed radiation from a person with a total surface area of 1.7 m². The skin temperature of the person is 303 K and they are absorbing radiation from the ambient 293 K. The 0.8 term represents an assumed average emissivity of 0.8 for the person.

We assume conduction through air can be neglected, and as usual we neglect convection because of its complexity. The entire radiating surface is at 303 K, so the person is not wearing a lot of thick clothing. (Perhaps a swimsuit.)

The unknown (x Cal / hr) works out to 41 Cal/hr, and it represents the calories needed to maintain the person’s skin temperature.
- Person is standing in shade (no directed radiation)
- Assume $e \approx 0.8$

$T_{\text{ambient}} = 20\degree C$

$T_{\text{skin}} = 30\degree C$

$A_{\text{skin}} = 1.7m^2$

Ambient radiation coming in.
Now it’s your turn. Work with your team to construct situations that correspond to the following equations.

**Equation 1:** The equation below describes an object undergoing some process. Solve for the unknowns, then construct a diagram depicting the process and explain a physical situation that could correspond to this description. Where necessary, provide a diagram of motion or energy flows.

*Bonus points* for the most realistic everyday situation

\[
x \text{ g/hr} \times \left(\frac{1 \text{ hr}}{3600 \text{ s}}\right) \times \left(\frac{10^6 \text{ J}}{1 \text{ MJ}}\right) \times \left(1 \text{ kg/1000 g}\right) \times 30 \text{ MJ/kg} \times 40\% = \\
\left[\left(0.1 \text{ W/K m}\right) \times \left(20^\circ \text{C} -10^\circ \text{C}\right) \times 2 \left(2\text{m} \times 3\text{m} + 2.5\text{m} \times 3\text{m} + 2\text{m} \times 2.5\text{m} \right)\right] / 0.15 \text{ m}
\]

**Equation 2:** The equation below describes an object undergoing some process. Solve for the unknowns, then construct a diagram depicting the process and explain a physical situation that could correspond to this description. Where necessary, provide a diagram of motion or energy flows.

*Bonus points* for the most realistic everyday situation

\[
1000 \text{ W/m}^2 \times \cos(75^\circ) \times 0.6 \text{ m}^2 \\
+ 5.67 \times 10^{-8} \text{ W/(m}^2 \text{ K}^4\right) \times 0.8 \times 1.7 \text{ m}^2 \times (293 \text{ K})^4 \\
= 5.67 \times 10^{-8} \text{ W/(m}^2 \text{ K}^4\right) \times 0.8 \times 1.7 \text{ m}^2 \times T^4
\]
Follow-up:

What do these two situations have in common?

How did you choose which physics principles would be relevant to each situation?
Tutorial 6B – Real Context

Phys 100 Tutorial 6

Today’s tutorial will use Jeopardy Questions to work on your ability to visualize and construct physics models. A Jeopardy Question is a question where you start with the equations and work backwards to construct the question that the equation is relevant to.

**Example Jeopardy Question:** The equations below describe an object undergoing some process. Solve for the unknowns, then construct a diagram depicting the process and explain a physical situation that could correspond to this description. Where necessary, provide a diagram of motion or energy flows.

\[ x \, W + 5.67 \times 10^8 \frac{W}{(m^2 \, K^4)} \times 0.8 \times (3 \, m^2) \times (3 \, K)^4 = 5.67 \times 10^8 \frac{W}{(m^2 \, K^4)} \times 0.8 \times (3 \, m^2) \times (243 \, K)^4 \]

**Example Solution:**

This equation represents a radiative energy balance with an extra power term on the left hand side. The right hand side temperature of 243 K is the surface temperature of a satellite with a surface area of 3 m². The left hand side temperature of 3 K corresponds to incoming radiation, so the ambient temperature is 3 K (which happens in space). The 0.8 term represents an assumed average emissivity of 0.8 for the exterior materials of the satellite. The addition of a power term represents the internal power supply of the satellite.

The extra heat \( (x \, \text{Watts}) \) works out to 1003 Watts, and it represents the extra heat needed in order to keep the temperature of the satellite at equilibrium.
Now it’s your turn. Work with your team to construct situations that correspond to the following equations.

**Equation 1:** The equation below describes an object undergoing some process. Solve for the unknowns, then construct a diagram depicting the process and explain a physical situation that could correspond to this description. Where necessary, provide a diagram of motion or energy flows.  

*Bonus points* for a realistic situation

\[
X \, \text{g/hr} \times (1 \, \text{hr}/3600 \, \text{s}) \times (10^6 \, \text{J}/1 \, \text{MJ}) \times (1 \, \text{kg}/1000 \, \text{g}) \times 30 \, \text{MJ/kg} \times 40\% = \frac{[(0.1 \, \text{W/(K m)}) \times (20 \, \degree \text{C} -10 \, \degree \text{C}) \times 2 \,(4 \, \text{m} \times 10 \, \text{m} + 4 \, \text{m} \times 20 \, \text{m} + 10 \, \text{m} \times 20 \, \text{m})]}{0.2 \, \text{m}}
\]

**Equation 2:** The equation below describes an object undergoing some process. Solve for the unknowns, then construct a diagram depicting the process and explain a physical situation that could correspond to this description. Where necessary, provide a diagram of motion or energy flows.  

*Bonus points* for a realistic situation

\[
1000 \, \text{W/m}^2 \times 0.75 \, \text{m}^2 \\
+ 5.67 \times 10^{-8} \, \text{W/(m}^2 \, \text{K}^4) \times 0.8 \times 3 \, \text{m}^2 \times (3 \, \text{K})^4 \\
= 5.67 \times 10^{-8} \, \text{W/(m}^2 \, \text{K}^4) \times 0.8 \times 3 \, \text{m}^2 \times T^4
\]
Follow-up:

What do these two situations have in common?

How did you choose which physics principles would be relevant to each situation?
So it’s time to put all of your different problem-solving skills together. This worksheet will guide you through all 5 steps of the problem solving process for the following problem.

Problem – Braking Distances

In experiment 1 you measured your reaction time while paying attention and while distracted. You are getting ready for your drive home one day and you know that you will need to make an important phone call and talk on the phone all the way across town. You don’t want to have an accident and hurt somebody else (or yourself!) but you reason that if you drive a little slower you could have the same stopping distance as another driver despite the fact you might be distracted.

Your owners’ manual tells you that your car has a curb weight of 1300 kg. You know that your car is capable of at least 0.6 g deceleration under wet conditions because that is the legally mandated minimum.

How much should you slow down?
Note: Not all of the details in these headers will be relevant each week... they are only intended to give you an idea of the types of information that are relevant to that step.

1. Interpret the problem
   - Carefully read and visualize the events described in the problem
   - If necessary, sketch a picture to clarify sizes, directions and spatial relationships
   - Clearly state the GOAL of the problem: what do you need to calculate and/or compare?
2. **Identify the relevant Physics Concepts**
   - List briefly the major physical principles that are relevant to this situation. (e.g. conservation of energy, Newton’s second law, 1-D kinematics with constant acceleration, etc.)
**Note:** Steps a) and b) are in a different order this week. Because so little information is given in this problem it makes sense to start thinking about our assumptions first. Thinking about the relevant information and the assumptions you’re going to make tends to happen at the same time, so feel free to go back and forth between these two steps as you work.

3. Create a Physics Model
   - A physics model summarizes all of the information relevant to solving the problem, including any assumptions you make.
   a) Define Physics Assumptions and Relationships
   - Using words and formulas as appropriate, interpret how the situation affects the physics variables defined in step 3b. Be sure to state all:
     - Limitations or constraints on the physical variables (e.g. $v < 0$)
     - Relationships between the physical variables (e.g. $a_1 = a_2$)
     - Simplifying assumptions (i.e. friction negligible, massless rope, constant acceleration etc.)
     - Initial conditions (i.e. $V_i = 0, a_i = -g$)
b) Make a Diagram and Summarize the Relevant Information

- Write down a description that summarizes all of the relevant information in the problem statement in a clear way. This could include pictures, equations, or descriptions, or any of the following, where appropriate:
  a. A statement of known and unknown quantities, with appropriate symbols defined
  b. Any intuitions or expectations about the answer. (e.g. “because of the situation in this problem, I would expect the speed of car B to be only a little bit faster than that of car A”)
- A specific physics diagram (free-body diagram, energy bar chart, motion diagram etc.)
- A coordinate system that specifies the reference and direction of measurement for any spatial variables. (e.g. “x = 0 is the tabletop, positive x is down” or equivalent symbols)

Make a simplified diagram that shows all of the dimensions relevant to this problem. Be sure to label the diagram with all of the relevant information, including everything you assumed above.
4. **Solve the Problem**
   - Show all calculations
5. **Check Your Answer (Error Checking / Sensemaking)**
   - Demonstrate that your result has the correct units
   - Compare results to known benchmarks
   - If necessary, perform additional calculations to check your answer is sensible
So it’s time to put all of your different problem-solving skills together. This worksheet will guide you through all 5 steps of the problem solving process for the following problem

**Problem – Braking Distances**

In experiment 1 you measured your reaction time while paying attention and while distracted. Because of this (and other) experience with physics you have been hired as an intern for the Vancouver traffic planning department. The city council is concerned about the studies that have shown that talking on a cellphone impairs a drivers’ reaction time while driving, and are considering implementing a ban on cellphones while driving. However, they want to investigate alternatives to a complete ban.

One potential solution is to have a *different* speed limit for drivers who are talking on their cellphone to compensate for the distraction. The idea is that if a distracted driver were moving more slowly, they might have the same braking distance as an alert driver. You investigate and find that an average car has a mass of 1300 kg, an average SUV has a mass of 1600 kg. The minimum legal deceleration for braking passenger cars is 0.6g under wet conditions.

Based on your calculations, what recommendations will you make to city hall?
Note: Not all of the details in these headers will be relevant each week... they are only intended to give you an idea of the types of information that are relevant to that step

1. Interpret the problem
   - Carefully read and visualize the events described in the problem
   - If necessary, sketch a picture to clarify sizes, directions and spatial relationships
   - Clearly state the GOAL of the problem: what do you need to calculate and/or compare?
2. **Identify the relevant Physics Concepts**
   - List briefly the major physical principles that are relevant to this situation. (e.g. conservation of energy, Newton’s second law, 1-D kinematics with constant acceleration, etc.)
Note: Steps a) and b) are in a different order this week. Because so little information is given in this problem it makes sense to start thinking about our assumptions first. Thinking about the relevant information and the assumptions you’re going to make tends to happen at the same time, so feel free to go back and forth between these two steps as you work.

3. Create a Physics Model
   • A physics model summarizes all of the information relevant to solving the problem, including any assumptions you make.

   a) Define Physics Assumptions and Relationships
   • Using words and formulas as appropriate, interpret how the situation affects the physics variables defined in step 3b. Be sure to state all:
     • Limitations or constraints on the physical variables (e.g. v < 0)
     • Relationships between the physical variables (e.g. \( a_1 = a_2 \))
     • Simplifying assumptions (i.e. friction negligible, massless rope, constant acceleration etc.)
     • Initial conditions (i.e. \( V_i = 0, a_i = -g \))
b) Make a Diagram and Summarize the Relevant Information

- Write down a description that summarizes all of the relevant information in the problem statement in a clear way. This could include pictures, equations, or descriptions, or any of the following, where appropriate:
  a. A statement of known and unknown quantities, with appropriate symbols defined
  b. Any intuitions or expectations about the answer. (e.g. “because of the situation in this problem, I would expect the speed of car B to be only a little bit faster than that of car A”)
  c. A specific physics diagram (free-body diagram, energy bar chart, motion diagram etc.)
  d. A coordinate system that specifies the reference and direction of measurement for any spatial variables. (e.g. “x = 0 is the tabletop, positive x is down” or equivalent symbols)

Make a simplified diagram that shows all of the dimensions relevant to this problem. Be sure to label the diagram with all of the relevant information, including everything you assumed above.
4. **Solve the Problem**
   - Show all calculations
5. Check Your Answer (Error Checking / Sensemaking)

- Demonstrate that your result has the correct units
- Compare results to known benchmarks
- If necessary, perform additional calculations to check your answer is sensible
Problem – Seat Belts

One of the most important systems in any vehicle is the seat belt, which stops the passengers’ forward motion when the vehicle stops. Its important not to stop the passengers TOO quickly though… a quicker stop means the force on the passenger is much higher and there is more risk of injury. This is why vehicles are designed to crumple during a crash: the longer stopping distance helps reduce the force on the passengers.

This piece of physics becomes very important to you when you are released from the hospital after being treated for a broken rib. The doctor has taped you up, but warns you not that any pressure on it will be painful and more than 450 N of force may cause more broken ribs or, even worse, internal damage.

A friend picks you up to take you home but you are worried that an emergency stop or an accident might re-injure your rib. You take a quick look in the drivers’ manual and find out that the stopping distance from 50 km/h is listed at 20 meters. In an accident, the car might come to a stop in as little as 1 meter. Based on that info, do you think it’s safe for you to drive home?
Note: Not all of the details in these headers will be relevant each week... they are only intended to give you an idea of the types of information that are relevant to that step

1. Interpret the problem
   - Carefully read and visualize the events described in the problem
   - If necessary, sketch a picture to clarify sizes, directions and spatial relationships
   - Clearly state the GOAL of the problem: what do you need to calculate and/or compare?
2. **Identify the relevant Physics Concepts**
   - List briefly the major physical principles that are relevant to this situation. (e.g. conservation of energy, Newton’s second law, 1-D kinematics with constant acceleration, etc.)
Note: Steps a) and b) are in a different order this week. Because so little information is given in this problem it makes sense to start thinking about our assumptions first. Thinking about the relevant information and the assumptions you’re going to make tends to happen at the same time, so feel free to go back and forth between these two steps as you work.

3. Create a Physics Model
   - A physics model summarizes all of the information relevant to solving the problem, including any assumptions you make.
   
a) Define Physics Assumptions and Relationships
   - Using words and formulas as appropriate, interpret how the situation affects the physics variables defined in step 3b. Be sure to state all:
     - Limitations or constraints on the physical variables (e.g. \( v < 0 \))
     - Relationships between the physical variables (e.g. \( a_1 = a_2 \))
     - Simplifying assumptions (i.e. friction negligible, massless rope, constant acceleration etc.)
     - Initial conditions (i.e. \( V_i = 0, a_i = -g \))
b) Make a Diagram and Summarize the Relevant Information

- Write down a description that summarizes all of the relevant information in the problem statement in a clear way. This could include pictures, equations, or descriptions, or any of the following, where appropriate:
  a. A statement of known and unknown quantities, with appropriate symbols defined
  b. A goal: a target quantity that needs to be calculated and/or any criteria for evaluating the result (i.e. “need to determine if V_max of car is > 20 km/h”)
  c. Any intuitions or expectations about the answer. (e.g. “because of the situation in this problem, I would expect the speed of car B to be only a little bit faster than that of car A”)
- A specific physics diagram (free-body diagram, energy bar chart, motion diagram etc.)
- A coordinate system that specifies the reference and direction of measurement for any spatial variables. (e.g. “x = 0 is the tabletop, positive x is down” or equivalent symbols)

Make a simplified diagram that shows all of the dimensions relevant to this problem. Be sure to label the diagram with all of the relevant information, including everything you assumed above.
4. **Solve the Problem**
   - Show all calculations
5. **Error Checking & Sensemaking**
   - Demonstrate that your result has the correct units
   - Compare results to known benchmarks
   - If necessary, perform additional calculations to check your answer is sensible
Problem – Tying down your cargo

A friend of yours is moving and you’ve reluctantly agreed to help. He has moved almost all of his stuff and now all that’s left to go is the refrigerator. The only places to tie it down are in on back wall of the bed of his pickup truck, so he plans to put the fridge as far back as it can go and then tie it with two ropes pointing straight back to the tie-spots on the tailgate.

He only has enough rope to tie it in two places, and asks you to help him check that the ropes won’t break if he has to make an emergency stop. You wisely point out that he should also consider what might happen if the truck has collision… you wouldn’t want the fridge to come loose and smash into the back of the passenger cab!

You estimate that the fridge weighs around 30 kg. The only rope he has available is some tie-down straps that are rated as having a 750 N maximum load. You take a quick look in the drivers’ manual and find out that the truck’s mass is 1500 kg and its stopping distance from 50 km/h is listed at 20 meters. In an accident, the truck might come to a stop in as little as 1 meter. Based on that info, do you think it’s safe for you to drive home?
Note: Not all of the details in these headers will be relevant each week… they are only intended to give you an idea of the types of information that are relevant to that step

1. Interpret the problem
   - Carefully read and visualize the events described in the problem
   - If necessary, sketch a picture to clarify sizes, directions and spatial relationships
   - Clearly state the GOAL of the problem: what do you need to calculate and/or compare?
2. **Identify the relevant Physics Concepts**

- List briefly the major physical principles that are relevant to this situation. (e.g. conservation of energy, Newton’s second law, 1-D kinematics with constant acceleration, etc.)
Note: Steps a) and b) are in a different order this week. Because so little information is given in this problem it makes sense to start thinking about our assumptions first. Thinking about the relevant information and the assumptions you’re going to make tends to happen at the same time, so feel free to go back and forth between these two steps as you work.

3. Create a Physics Model
   - A physics model summarizes all of the information relevant to solving the problem, including any assumptions you make.

a) Define Physics Assumptions and Relationships
   - Using words and formulas as appropriate, interpret how the situation affects the physics variables defined in step 3b. Be sure to state all:
     - Limitations or constraints on the physical variables (e.g. $v < 0$)
     - Relationships between the physical variables (e.g. $a_1 = a_2$)
     - Simplifying assumptions (i.e. friction negligible, massless rope, constant acceleration etc.)
     - Initial conditions (i.e. $V_i = 0$, $a_i = -g$)
b) Make a Diagram and Summarize the Relevant Information

- Write down a description that summarizes all of the relevant information in the problem statement in a clear way. This could include pictures, equations, or descriptions, or any of the following, where appropriate:
  a. A statement of known and unknown quantities, with appropriate symbols defined
  b. A goal: a target quantity that needs to be calculated and/or any criteria for evaluating the result (i.e. “need to determine if Vmax of car is > 20 km/h”)
  c. Any intuitions or expectations about the answer. (e.g. “because of the situation in this problem, I would expect the speed of car B to be only a little bit faster than that of car A”)
- A specific physics diagram (free-body diagram, energy bar chart, motion diagram etc.)
- A coordinate system that specifies the reference and direction of measurement for any spatial variables. (e.g. “x = 0 is the tabletop, positive x is down” or equivalent symbols)

Make a simplified diagram that shows all of the dimensions relevant to this problem. Be sure to label the diagram with all of the relevant information, including everything you assumed above.
4. Solve the Problem
   • Show all calculations
5. Error Checking & Sensemaking

- Demonstrate that your result has the correct units
- Compare results to known benchmarks
- If necessary, perform additional calculations to check your answer is sensible
Main Question – Gas Mileage

Problem:
You and two friends are travelling to California for a vacation. The driver is in a hurry to get there, and has been driving a little over the speed limit on the highway, but your friend in the back keeps trying to convince him to drive slower. You have all agreed to split the gas costs and he says driving slower will be cheaper for everyone. (He is a very thrifty person) The driver doesn’t think that the amount of gas saved will be worth it, so he just keeps on driving.

You are also on a tight budget and would like to save some money, so after listening to them argue for 20 minutes you decide to try to figure out the answer so you can settle it. You dig around in the glove box and come up with the car’s owner’s manual, which tells you that the empty weight of the car is 1300 kg and the car is 2 m wide and 1.4 m high. You know that modern gasoline engines are around 21% efficient at converting chemical energy into mechanical energy, and gasoline has 35 MJ / liter of chemical energy. You look up the Drag Coefficient on your friends’ iPhone ($C_D = 0.28$) and you recall from your physics class the relevant coefficients of friction for a car: the coefficient for kinetic friction of rubber on asphalt is around 0.6, for static friction is around 0.75, and the coefficient of rolling friction for a car is about 0.02.

At highway speeds, how much difference does it make to the fuel economy to drive 10% more slowly? Over the course of the trip to California (1600 km) how much money could you save on gas?
1. Interpret the problem
2. Identify the relevant Physics Concepts
3. Create a Physics Model

Make a Diagram and Summarize the Relevant Information

- Note: Any variables you use in your equations must be depicted or explained in your model.

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Define Physics Assumptions and Relationships

Your assumptions should be *justified* by reference to your experience, direct measurements, or the textbook / course notes.
4. Solve the Problem
6. **BONUS [2 points]**
The car’s owners manual lists its highway fuel economy as 6.8 liters / 100 km. What speed did the automakers use to determine this number?
Main Question – Gas Mileage

Problem:
You are working as a consultant for a courier company that carries a lot of packages to Kelowna and back. You are trying to come up with a recommendation for company policy on how fast the drivers should drive. The company is trying to save money and you have decided to find out how much money the company could save by having the drivers slow down by 10%.

The company has a fleet of courier vans that weigh 4300 kg when fully loaded. The owner’s manual tells you that these vans are 2 m wide and 2.1 m high. You know that modern gasoline engines are around 21% efficient at converting chemical energy into mechanical energy, and gasoline has 35 MJ / liter of chemical energy. You look up the typical Drag Coefficient for a van on the internet ($C_D = 0.39$) and you recall from your physics class the relevant coefficients of friction for a car: the coefficient for kinetic friction of rubber on asphalt is around 0.6, for static friction is around 0.75, and the coefficient of rolling friction for a car is about 0.02.

At highway speeds, how much difference does it make to the fuel economy to drive 10% more slowly? If one van makes 50 trips to Kelowna each year, how much money could the company save on gas?
1. Interpret the problem
2. Identify the relevant Physics Concepts
3. Create a Physics Model

Make a Diagram and Summarize the Relevant Information

- Note: Any variables you use in your equations must be depicted or explained in your model.

Define Physics Assumptions and Relationships

Your assumptions should be justified by reference to your experience, direct measurements, or the textbook / course notes.
4. Solve the Problem
BONUS [2 points]
The van’s owners manual lists its highway fuel economy as 18 liters / 100 km. What cruising speed did the automakers use to determine this number?
Appendix B Exploratory Post-Course Interview Protocol

Demographics (first interview):

★ How old are you?

★ What is your major in school?

★ Can you tell me a little about why you choose that major?

★ What year are you in?

★ [ IF YEAR > 1 ] Did you do your earlier studies at UBC?

★ What is your favorite class? Why?

★ What do you want to do when you graduate?

★ Why did you volunteer for this study?
Real-World Connection Beliefs Questions

“I’ll read these statements to you, and I’d like you to reply by letting me know whether you agree or disagree with them on a scale of 1 to 5, 1 being strongly agree, and 5 being strongly disagree.”

Learning physics changes my ideas about how the world works.
- can you give an example of anything that changed your idea about how the world works?
  - why do you think that changed your idea?

- was there anything the prof did that affected how you think about the world?
  - do you think there’s anything the prof COULD do?

Reasoning skills used to understand physics can be helpful to me in my everyday life.
- what makes you say that?
- what type of “reasoning skills” do you think of when you read this question?
- do you think a physics course should attempt to teach you these type of reasoning skills?
- can you think of any real-life situation where they could be helpful?
  - maybe to somebody else?
  - someone with a particular job, or problem?
- do you think any aspect of the course attempted to give you these reasoning skills?

To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.
- can you give an example of any experience you’ve had that would be relevant to a physics problem?
- do you think other students would be able to relate to this situation?

The subject of physics has little relation to what I experience in the real world.
- was there anything the prof did to attempt to connect physics to your experience in the real world?
  - was it successful? why / why not?
  - what about other aspects of the course... tutorials? labs?
Problem-Solving Beliefs Questions
“I’ll read these statements to you, and I’d like you to reply by letting me know whether you agree or disagree with them on a scale of 1 to 5, 1 being strongly agree, and 5 being strongly disagree.”

Generic follow-up questions
• can you explain why you feel that way?
• were there any particular situations in phys 100 where this came up? can you give an example?
  o in class? on tests? in tutorials? labs?
• do you think your prof addressed this issue in particular?

13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.
15. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.
16. Nearly everyone is capable of understanding physics if they work at it.
34. I can usually figure out a way to solve physics problems.
42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.
5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.
21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.
22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.
Appendix C Structured Real-World Connections Interview Protocol

Questions for the Interviewer to Ask

How old are you?

What is your major?

What do you want to do with your degree?

What is your favorite course? Why?

How did you hear about this study?

Why did you decide to sign up for the study?

How long has it been since you took a science course?
Agree or Disagree with the following statements

“I’ll read these statements to you, and I’d like you to reply by letting me know whether you agree or disagree with them on a scale of 1 to 5, 1 being strongly agree, and 5 being strongly disagree.”

Learning science changes my ideas about how the world works.

Reasoning skills used to understand science can be helpful to me in my everyday life.

To understand science, I sometimes think about my personal experiences and relate them to the topic being analyzed.

The subject of science has little relation to what I experience in the real world.
QUESTIONS TO ASK AFTER STUDENT CONSIDERS EACH PROBLEM

1. DO YOU SEE THIS AS CONNECTED TO THE RW?
2. Do you think that learning more about the topic of this would be useful in your life? Why or why not?
3. Would thinking about any of your own experiences help you to interpret OR SOLVE this question /statement? Can you give an example?
4. What kind of person might find (the solution to a question like this / this statement) useful?

What are some ways that this question / statement is connected to the real world?

What are some ways that this question / statement is NOT connected to the real world?

What is your opinion: connected or not?

What kind of person might find (the solution to a question like this / this statement) useful?
Problems for the Participants to Consider

The following problems and statements will be used for discussion with your interviewer. You do NOT need to solve each problem, but you might want to think about how you would solve them.

Emperor Penguins live in Antarctica where the outside temperature can be -10 °C for long periods of time. The penguins must maintain their body temperature of 38 °C in order to survive. Assume the penguin has a layer of feathers 2.0 cm thick with a conductivity of 0.030 W/m °K and that the total surface area is 1.1 m².

a) How much heat does a penguin lose to the surrounding environment due to thermal conduction each hour?

b) How many kg of fish must a penguin eat (on average) in 24h to maintain its body temperature? 1 kg of fish (cod) has 3.43 kJ.
A landscaping contractor needs to purchase a new vehicles to run his business. He is considering the purchase of an $18,000 truck that burns 7.7 liters / 100 km and has a maximum payload of 750 kg or a $29,000 truck that burns 9.7 liters / 100 km and has a payload of 1,300 kg. He usually works on one job in Vancouver each week, and needs to haul around 800 kg of rock, sand, and other materials from a gravel pit in North Vancouver to each job.

Which truck will burn less fuel over the course of a year?  
Which truck will prove to be a cheaper investment during this time?
Galapagos finches

Scientists have long believed that the 14 species of finches on the Galapagos Islands evolved from a single species of finch that migrated to the islands one to five million years ago (Lack, 1940). Recent DNA analyses support the conclusion that all of the Galapagos finches evolved from the warbler finch (Grant, Grant & Petren, 2001; Petren, Grant & Grant, 1999). Different species live on different islands. For example, the medium ground finch and the cactus finch live on one island. The large cactus finch occupies another island. One of the major changes in the finches is in their beak sizes and shapes, as shown in this figure.

What would happen if a breeding pair of finches was placed on an island under ideal conditions with no predators and unlimited food so that all individuals survived? Given enough time
a. the finch population would stay small because birds only have enough babies to replace themselves.
b. the finch population would double and then stay relatively stable.
c. the finch population would increase dramatically.
d. the finch population would grow slowly and then level off.
A typical person in Vancouver commutes 22 km to their job. Estimate the amount of money saved annually by a person who commutes by bicycle instead of owning and operating a motor vehicle.
A and B are identical balls which roll down the smooth ramps shown in the figure below. They are both released from rest at the top of the ramp, and their speeds at the bottom are $v_A$ and $v_B$. Which ball is moving faster at the bottom of the ramp?
Consider the scientific information in the following newspaper article. It is not a question, but think about how this information might be relevant to your life.

An explosion of sightings of reddish-brown jellyfish have sparked the curiosity of residents around Vancouver Island and the Lower Mainland -- but a marine biologist says the surge is just a natural part of the creatures' life cycle.

Mary Arai, a marine biologist with the University of Calgary who is currently a senior investigator at the Pacific Biological Station in Nanaimo, said yesterday the Cyanea capillata jellyfish being spotted in the shallows and shores around the Island are at the top of a four-year population cycle.

While some wonder whether the surge is connected to climate change, Arai said history proves otherwise. "It's been going on for hundreds of years, so no," she said.

It's not known why the population runs in the four-year cycle, although Arai noted that the jellyfish's population tends to go up in years that the fish populations drop.

"We don't entirely know why," Arai said.
Chlorofluorocarbons (CFCs) are decomposed by UV radiation from the sun in the *ozone destruction cycle*, shown below:

1) \( \text{CFC} + h\nu (\lambda < 260 \text{ nm}) \rightarrow \text{Cl}^* + \text{CFC residue} \)

2) \( \text{Cl}^* + \text{O}_3 \rightarrow \text{ClO}^* + \text{O}_2 \)

3) \( \text{ClO}^* + \text{O} \rightarrow \text{Cl}^* + \text{O}_2 \)

Which of the following could lead to increased ozone destruction?

1) An increase in the intensity of the UV radiation
2) An increase in the wavelength of the UV radiation
3) A decrease in the wavelength of the UV radiation
4) An increase in the frequency of the UV radiation
It is a common myth that the water in sinks and toilets drains in opposite senses in the Northern and Southern Hemisphere, and that this is due to the Coriolis Effect.

The Coriolis Effect is real, due to the rotation of the Earth, but the force it seems to exert on freely moving objects is actually imaginary. The deflections are a result of our observing the motions in our rotating reference frame. The Coriolis force $F_{\text{Coriolis}}$ (in units of Newtons (N)) on an object of mass $m$ (kg) moving with a velocity $v$ (m/s) in a reference frame rotating with angular velocity $\omega$ (the lower-case Greek letter “omega”) is given by:

$$F_{\text{Coriolis}} = -2 m (\omega \times v)$$

The angular velocity $\omega = d\theta/dt$ of the rotating reference frame is given in radians per second.

1. Estimate the sideways acceleration the water will feel due to the Coriolis force as it drains out of a typical sink.

2. Do you think this is enough acceleration to force the water to drain in a counterclockwise sense?
On a very chilly winter evening you go to a restaurant and the waiter offers you a table near the window. You are already feeling cold and ask for a different table, saying that it’s always colder near the window. The waiter argues that the restaurant has new double-paned windows so there should not be any difference. You can beat him with a physics argument saying that

1. The window is mostly transparent in the infrared. Therefore it radiates less heat back into the room.
2. The window is thinner compared to the walls. Therefore more heat is lost due to conduction.
3. There is always a draft near the window.
4. The window is transparent in the visible wavelength range. Therefore your body loses more heat.
Consider the scientific information in the following newspaper article. It is not a question, but think about how this information might be relevant to your life.

The sun's winds are less blustery than they used to be, NASA said on Tuesday, revealing data from a solar probe that promises new insights about Earth's local star.

The data show the solar wind, a steady stream of charged sub-atomic particles emitted by the sun and blowing at 1 million mph (1.6 million kph), has dwindled to its lowest level in at least 50 years, reducing its strength as a shield against potentially harmful galactic cosmic radiation.

Scientists studying the phenomenon insist Earth's inhabitants have nothing to fear. Humans remain protected from cosmic rays by virtue of the magnetic field that surrounds Earth, acting as an inner barrier to our exposure.
Appendix D Epistemological Framing Coding Rubric

Key Principles

- Frames are coded largely with the group as the unit of analysis. We look for the whole group shifting their collective focus.

- Frames are coded first on characteristics of speech rather than content: students’ tone of voice, rhythm of speech, whether they are speaking / responding to each other, sound of pages flipping, sound of writing, long silences.

- Frames are coded next on the implicit goal of their speech.

- Isolated single statements in a new frame don’t get coded
- Statements are isolated when they get ignored by the group
- If a single statement is more than a few seconds AND the group responds to it and/or it captures the attention of the group then code it.
- For brief statements in a new frame that catalyze a transition to a third frame, MARK them so we discuss them later.

- For any frame transition, code from the first statement where there’s clear evidence of a transition. If it’s very clear from the first statement and gets taken up by the group, then code the first statement.

- For an ambiguous statements, code the first statement where it’s CLEAR that you are in a new frame.

- We code TWO simultaneous frames (ie. Split frame) when there is clear evidence of two independent conversations with different participants. (i.e. talking over each other). Use * to mark the beginning and end of frames in Fr2. Frame 1 is the one that “wins” at the end.

- We code a Mixture of frames when there is a persistent framing mismatch between two groups of students who are in conversation with each other.

- If you see a frame change happening in the middle of a statement split the statement and code each half independently. Mark the split statement with a purple background.

Frame Definitions

O (OTHER)

What you did this weekend
Comments on other aspects of the course
Students joking or flirting with each other
Includes sarcastic comments with some physics content (but still clearly intended to be humorous)

**M: META discussions about the tutorial** This is for frames where the group is evaluating the structure of the tutorial according to their own experience. (Mostly sarcastic comments about “that would never happen”)
- Comments on reasonableness of the tutorial situation
- Comments on reasonableness of values presented in the tutorial

**G for explicit negotiations of group roles.** (with an option to include other logistical discussions in here later)
- Student’s conception of their task is to figure out group roles and/or tasks associated with group roles
- This is different than students giving each other instructions where their group role is already understood.
- “want me to write?”
- “who’s the explainer?”

**TA (TA Focus)**
- Students are focused on / talking to TA.
- Very limited discussion with each other
- Most statements addressed to / from TA.

**D (Discussion focus).**
- Students talk over each other
- Respond to each others’ ideas directly
- Expand on each others’ ideas
- Rapid exchange of ideas
There are TWO TYPES of discussion, based on the implicit goal.

**D1: procedural discussion.** GOAL is to make progress towards the answer of the worksheet. Interpreting what the instructor / worksheet is asking for. Satisfying the different steps of the process. Getting an answer on the page
  - focused on the worksheet, satisfying worksheet structure
  - procedural – “what do we do next?”
  - discussion of “what we’re supposed to do”, “should”
  - “what we’re calculating”
  - “we can do X or Y”
  - “what do we need to do”
  - discussion of assumptions framed as a list of things to satisfy worksheet condition
  - Interpretation of consistency of mathematics
  - Evaluation of results that is brief, shallow, parrots prior work / authority.
  - Quick connection to real world quantity, but isn’t consequential. No evidence that they make any sense of it or connect to anything else. (e.g. translation from K into °C with no further discussion)
  - EXPLANATION: one student is using small bits of conceptual connections to explain to other students what they should DO. But they key focus of the conversation is what are we doing, what to write / do etc.
  - Paraphrasing of tutorial.

**D2: conceptual discussion.** Primary GOAL is to interpret / understand what’s going on. It doesn’t have to be a translation to PHYSICS representations.
  - focused on understanding the physics of what’s happening
  - reference to students’ own intuition or commonsense
  - conceptual interpretation of the given problem / situation
    - interpretation of words -> visualization or narrative in a way that makes sense to the students.
  - conceptual interpretation of mathematical structure. “this part is the heat in, and this part is the heat out”
  - discussion of assumptions framed as what makes sense.
  - Interpretation of MEANING of mathematics, or MEANING / concept / narrative of what’s happening in the question
  - Evaluation of result by “looking at the big picture”
  - Coordination of representation “Vf is zero because it stops”
  - A review of what’s happened so far with emphasis on the conceptual meaning of the mathematics
W: Worksheet focus
THREE MAIN BEHAVIORS
  o Mumbling under their breath
    § Mumbling
    § Short sentences
    § Long silences
    § Flipping pages
    § Students mumbling or silent
  o Reading the worksheet
  o One (or more) student(s) directing another about what to write
    § No protracted discussion – limited usually to a single question and answer
    § Giving directions
    § Possibly asking short questions about what to write on the page that have direct concrete answers. Often the answers are delivered in a clipped or low tone of voice.
    § No exchange of ideas – just getting things down on the page
    § Short clipped speech. Not dynamic.
Rules of Thumb for resolving ambiguities

Distinguishing between W and D1

- Listen to the tone and rhythm of speech. I find this the most telling indicator of the W frame
  - W frame students speak with flat intonation. They may respond to questions but both question and response are direct and clipped. There is no back-and-forth.
  - D1 students have much more variety in tone of voice. They may have back and forth discussion about the same issue. They may respond to each other more quickly than in W frame.

- In your mind’s eye imagine the students’ posture. In W frame they are bent over looking at the worksheet. In D1 frame they are discussing with each other

- If students are all talking at the same time in an animated fashion it’s D1 rather than W

- If several students are talking but they are only giving directions to the person with the pen then it’s W

Rules of Thumb:

- Two statements (e.g. question and response) is enough to code a frame.
- Generally speaking, don’t code a single statement as a frame change unless it is protracted and there is evidence that it captures the attention of the whole group. If a statement is in a new frame but triggers a protracted shift into a third frame, code the third frame.

- If coding is ambiguous and there is no evidence of a frame TRANSITION continue in the existing frame

- Reading from an external piece of information or from the worksheet should be coded as a frame shift if it takes over the group attention. If it is adding to the discussion that the group is already having, then it is not a frame shift.
  - Reading from the worksheet – default is to code this as W frame unless its clearly a part of a discussion. E.g when the students are starting the problem or re-starting after being temporarily stuck
  - EVEN IF IT’S ONLY ONE LINE

- If there are breaks in the conversation because they are actually thinking about something just said, that should still be part of the frame. However, long pauses where we have no idea what is going on should be marked as "?” or "O" as discussed. So what’s long? 15-20 seconds seems like a reasonable threshold to start with
  - If it’s a long silence with on-task work on either side, it is likely a W and should get coded as such

- A split frame where we have some of the group off task and some in W gets marked as a Holding Pattern.

- General trigger for D2: translation of representation. i.e. interpreting (and understanding) mathematics in terms of narrative or context. the implicit goal is more important than this, but this is a good rule of thumb. We expect to be seeing a lot of this in the jeopardy questions.
• Rule of thumb: Reading from Worksheet: Gets coded as W unless it is in service of an ongoing discussion.
• Rule of thumb: Interpreting of results: only counts as D2 if it's geared towards qualitative / conceptual understanding of the result. Mere algebraic discussions counts as D1
Appendix E Real-World Connections Coding Rubric

Overall guidelines

- The unit of analysis is a single statement
- We may generate false positives where students are just reciting something learned in physics class, BUT I think the overall arguments will still hold. Feel free to note any codes that you think might be false positives.

Main Codes

- (A) Assumption - using outside knowledge to make assumptions or define a relationship.
  - Translation of representation from conceptual/narrative -> mathematical
  - Template is “because of X in the real world, we do Y with our calculation
  - This can be anything from students assuming the speed of a car = 50 km/h to more "physics-y" stuff where they assume that e=1 for a given emitter. In the latter case they have clearly learned it in physics class, but my current theory is that these cases will be in the minority and what we will mostly be capturing is the "everyday" connections.
  - BALD ASSUMPTUIONS do not get coded.
    - These are assumptions that are BOTH not explicitly connected to a real-world situation AND mathematically convenient
    - If they just say e=1, that’s a bald assumption. If they say “it’s basically black, so we can use e=1” they have connected to the story.
  - Discussing the quantity that needs to be assumed is not the same as actually making an assumption. No code.

- (I) Tutorial Interpretation – interpretation of what’s written in the tutorial
  - translation of representation from more abstract forms (such as jargon or formulae) into everyday language / concepts / narrative

- (V) Interpretation & Evaluation - students use their existing knowledge to evaluate an answer or idea that emerges during the tutorial.
  - translation of representation from more abstract forms (such as jargon or formulae) into everyday language / concepts / narrative
  - Strict mathematical comparisons are NOT an evaluation
  - “that’s enough for a cookie” – evaluation of result in terms of real world
  - “it should not take more than 5 seconds”. Gets coded as evaluation because that’s clearly what he is doing
• justified evaluation – the kind that would get credit if they turned it in
• unjustified evaluation – “that’s fast”,
• (Z) Personalizing – interpreting tutorial results in terms of themselves WITHOUT making an evaluation
  • more about putting themselves into the scenario
  • personalization: translation to place the narrative / concepts in the tutorial in students’ everyday situation
    ▪ “which two friends should I take?”
    ▪ “yes, buy me a keychain”
• (M) Meta-statement about sensibleness or reasonableness of the tutorial itself.
  • E.g. “i doubt you would actually do these calculations”
• (P) Prompt for RWC. statements and questions that lead to a RWC
  • these are not a code! They should go in the comments field
  • “they don’t even give us the gas prices”

Modifiers
• (+) Elaborations: implied to be referencing the last ExC statement.
• (-) Repeat / Recap: a statement that has no new ideas. Repeating stuff that was said earlier
  • CRITERIA FOR A (-) CODE
  • Straight repeat of a number or assumption stated earlier
    ▪ “that’s big. Yeah, that’s big”
  • Discussing an assumption and propose a new number with NO support or justification
    ▪ “100. No, 60. How about 90?”
• (*) Justified statements. Have more than one idea connected within a single statement.
  • E.g. evaluating w.r.t something specific. “that’s enough money for a cookie”

Rules of Thumb
• Dealing with questions:
  • General questions (what is going on here?; do we need anything else?) get COMMENTED as prompts
  • Specific questions that are prompting RWC (Should we take into account the seasons?) get coded as the type of RWC they are prompting. Usually A. The TEST IS: if this question, phrased as a statement were a RWC, then code it as such.
• When students are brainstorming a value, merely suggesting a new number with no justification gets a (-) modifier. No new ideas
• Repeating a value that was estimated or assumed earlier does not get a repeated ExC code if the students are now talking about it purely in terms of the calculation
• Citing an external source = justification (*)
• Remember these transcripts were coded by poorly-paid monkeys that had recently been laid off from the Shakespeare typewriter project. When things are ambiguous or the discussion is fast and furious doublecheck the transcript with the original audio.
GUIDELINES FOR CODING WITH +- 3 SECOND ERROR (A.K.A. FLAG-BASED CODING)

FLAG real world assumptions

- Flags have some spread. Nominally 3 seconds (average length of one statement), but we might expand this if we have a good reason to.
- If our flags overlap, then we code that as a match.
- If flagged regions don’t overlap by more than 3 seconds, we code the difference
- We don’t really care WHAT KIND of code, only that it is some kind of ExC

Issues that have led us to this model:

- It’s very difficult to make a clean distinction between new and old ideas
  - People restate, rephrase, and make small elaborations on each others’ statements all the time
- Because of this fact, our codes of NEW vs. OLD ideas don’t match up very well.

Analysis at the level of a statement doesn’t match with how ideas are brought up and used within a group-problem solving context

- Usually brought up and discussed or argued etc.

RWC don’t always reside “in” a particular statement

- They are often shaped over several statements and several people
- E.g. a prompt is a question or a bid for a RWC that gets the group to consider their RW knowledge. This is a key part of making RWC but it isn’t the connection itself. By the same token, it would be silly to think of the later statement as being a RWC on its own, seeing as it was prompted earlier
- ARGUMENT IS: WE CODE ON A +- 3 SECONDS BASIS BECAUSE WE BELIEVE THAT THIS MORE CLOSELY REPRESENTS THE NATURE OF RWC MADE IN GROUP DISCUSSIONS
- Could quantify this... the average statement length is 3 seconds. We are just saying this is +- 1 statement so a flag is basically 2 statements long. It takes two to tango.

PROBLEM with this is that an isolated statement would get double the weight.

- Seems OK. When somebody comes up with something out of the blue it gets more weight than when they riff off of another in conversation. Maybe this is OK.