

---

# Contents

<b>List of Figures</b>	<b>vii</b>
List of Figures . . . . .	ix
<b>List of Tables</b>	<b>xi</b>
List of Tables . . . . .	xiii
<b>Glossary</b>	<b>xvi</b>
<b>1 Introduction</b>	<b>1</b>
<b>2 Literature Review</b>	<b>5</b>
2.1 Introduction . . . . .	5
2.2 Problem-Solving Competence . . . . .	5
2.2.1 Definition of Problem and Problem-Solving Competence . . . . .	6
2.2.2 Definitions of Complex Problem-Solving (CPS) . . . . .	8
2.2.3 Analytical and Dynamic Sides of Problem-Solving Competence .	11
2.2.4 Cognitive Processes of Problem-Solving . . . . .	12
2.2.5 Collaborative Problem-Solving . . . . .	14
2.2.6 Problem-Solving Models . . . . .	16
2.2.7 Factors Affecting Problem-Solving Competence . . . . .	25
2.2.8 Covariates of Problem-Solving Competence . . . . .	29
2.2.9 Successful/Unsuccessful Problem-Solvers . . . . .	30
2.2.10 Problem-Solving in Chemistry Education . . . . .	32
2.3 Assessing Problem-Solving Competence . . . . .	35
2.3.1 Importance of Assessing Complex Problem-Solving Competence	37
2.3.2 Paper and Pencil Instruments . . . . .	38
2.3.3 Computer Based-Problem-Solving Assessment . . . . .	39
2.4 Gamification . . . . .	55

---

2.4.1	Gamification Definition . . . . .	56
2.4.2	Gamification Elements . . . . .	58
2.4.3	Types of Gamification . . . . .	61
2.4.4	Game Design Rules . . . . .	62
2.4.5	Gamification in Education . . . . .	62
2.4.6	Case Studies of Gamification in Education . . . . .	64
2.4.7	Gamification and Problem-Solving . . . . .	67
2.4.8	Advantages and Disadvantages of Gamification . . . . .	68
2.5	Motivation and Learning Theories . . . . .	71
2.5.1	Motivational Theories and Models . . . . .	71
2.5.2	Changing Behavior . . . . .	74
2.5.3	Learning Theories . . . . .	76
2.6	Design Video Game-Based Gamification Elements . . . . .	83
2.6.1	Requirements for Designing and Developing Educational Video Games . . . . .	83
2.6.2	Game Development Models . . . . .	84
2.7	Research Gaps and Research Questions . . . . .	91
2.7.1	Research Questions . . . . .	93
2.8	Objectives and Significance of the Research . . . . .	95
2.8.1	Objectives of a Solution . . . . .	95
2.8.2	The Significance of this Research . . . . .	96
2.9	Summary . . . . .	96
<b>3</b>	<b>Research Methodology and Instruments</b>	<b>97</b>
3.1	Introduction . . . . .	97
3.2	Research Approach . . . . .	97
3.2.1	Design Science Research Methodology (DSRM) . . . . .	98
3.2.2	Design Science Research Method (DSRM) and Links to Chapter Thesis . . . . .	99
3.3	Research Instruments . . . . .	113
3.3.1	Sample . . . . .	113
3.3.2	ALCHEMIST . . . . .	117
3.3.3	Problem-Solving Questions and Tasks . . . . .	117
3.3.4	In-depth Interview . . . . .	120
3.3.5	Think-Aloud Protocol (Think-Aloud Protocol (TAP)) . . . . .	122
3.3.6	Coding Manual . . . . .	123
3.3.7	Questionnaire (Game Evaluation) . . . . .	125
3.3.8	Pupils Testing Instruments . . . . .	127
3.3.9	MicroDYN . . . . .	128

---

3.4	Research Methodology Limitations . . . . .	128
3.5	Summary . . . . .	129
<b>4</b>	<b>Design Framework</b>	<b>131</b>
4.1	Introduction . . . . .	131
4.2	Game Design Model . . . . .	131
4.2.1	Analysis and Exploratory Study . . . . .	133
4.2.2	Game Design "ALCHEMIST" . . . . .	143
4.2.3	ALCHEMIST Development . . . . .	147
4.2.4	Quality Assurance . . . . .	150
4.2.5	Implementation and Evaluation . . . . .	150
4.3	Discussion and Conclusion . . . . .	151
4.4	Summary . . . . .	153
<b>5</b>	<b>Demonstration and Results</b>	<b>155</b>
5.1	Introduction . . . . .	155
5.2	Phases of Data Collection . . . . .	155
5.3	Study I: Evaluation Study . . . . .	156
5.3.1	Study Design . . . . .	156
5.3.2	Sample Description . . . . .	158
5.3.3	Analysis and Results of TAPs . . . . .	161
5.3.4	Analysis and Results of the Post-Questionnaire . . . . .	165
5.3.5	Summary of the Evaluation Study Results . . . . .	186
5.4	Study II: Validation Study . . . . .	187
5.4.1	Study Design . . . . .	188
5.4.2	Study Variables and Covariates . . . . .	189
5.4.3	Descriptive Analysis and Results . . . . .	190
5.4.4	Inferential Analysis . . . . .	206
5.5	Pre and Post Content Knowledge Test . . . . .	212
5.5.1	Summary of the Validation Study Results . . . . .	213
5.6	Summary . . . . .	213
<b>6</b>	<b>Discussion</b>	<b>215</b>
6.1	Introduction . . . . .	215
6.2	Discussion of the Observation of the Problem-Solving Phases during the Gameplay . . . . .	215
6.3	Discussion of Design Propositions Resulting from the Game Evaluation Study . . . . .	217
6.4	Discussion of the Results from the Game Validation Study . . . . .	223
6.5	Summary . . . . .	226

---

<b>7 Conclusion and Summary</b>	<b>227</b>
7.1 Introduction . . . . .	227
7.2 Overall Summary . . . . .	227
7.3 Answering the Research Questions . . . . .	229
7.4 Contributions . . . . .	231
7.4.1 Contribution to Chemistry Education . . . . .	232
7.4.2 Contributions to Practice and Industry . . . . .	232
7.5 Limitations and Suggestions for Future Research . . . . .	233
7.5.1 Future Research . . . . .	234
7.6 Summary . . . . .	235
<b>Bibliography</b>	<b>237</b>
<b>A Appendices</b>	<b>269</b>
A.1 Instruments . . . . .	269
A.1.1 Teachers' In-depth Interview Guide (Exploratory study) . . . . .	269
A.1.2 Pupils' In-depth Interview Guide (Exploratory study) . . . . .	271
A.1.3 Coding Manual for Interviews . . . . .	273
A.1.4 ALCHEMIST Game Quiz . . . . .	274
A.1.5 Summary of the Implemented Scientific Content . . . . .	277
A.1.6 Game Features . . . . .	281
A.1.7 Pupils Interview Guide (Game evaluation phase) . . . . .	285
A.1.8 Introduction and Exercises for Thinking-Aloud . . . . .	286
A.1.9 Guide to the Coding of the Thinking-Aloud Protocols . . . . .	287
A.1.10 Coding Manual for TAPs . . . . .	289
A.1.11 Code-lines . . . . .	294
A.2 Data Collection . . . . .	295
A.3 Data Analysis . . . . .	298
A.3.1 Descriptive Analysis (Evaluation Study) . . . . .	298
A.3.2 Simple Mediation Analysis (Validation Study) . . . . .	310