DESIGNING A TECHNOLOGY ENHANCED LEARNING ENVIRONMENT FOR HYPOTHETICO-DEDUCTIVE REASONING IN GENETICS

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Hypothetico-deductive reasoning is an important skill for pursuing science. Students face difficulties in developing hypothetico-deductive reasoning. In this paper, we propose the design of a technology-enhanced learning environment, Geneticus Investigatio, which aims to develop hypothetico-deductive reasoning in the domain of genetics education for undergraduates. In this system, the student has to choose different hypotheses for a given problem, design experiments based on the hypothesis, predict the outcome of experiment, run simulations to test the prediction of the experiment, compare predicted and observed outcomes and accept or reject the hypothesis. The system requires that student reason at each and every step. Students are provided with scaffolds in designing of experiment and prediction based on designed experiment. This system utilizes the affordances of technology enhanced learning environment like variable manipulation in simulation, immediate and customized feedback and self-paced learning.

INTRODUCTION

Any concept in science requires scientific reasoning for its understanding. "Scientific reasoning can be conceptualized as using a set of mental rules, plans, or strategies to devise causal inferences for a phenomenon that is beyond direct observation."(Lawson 2004).According to this definition five subset of skills are crucial components which are hypothetico-deductive reasoning, control of variables, proportional reasoning, co-relation reasoning and probabilistic reasoning (Koslowski, 1996; Zimmerman, 2000; Lawson, 2004). This is indeed a problem because mostly causal inference behind any observation is difficult to comprehend. This comprehension is necessary for understanding of various scientific processes. For example, in a real situation, it is difficult to infer the blood group of the parents given the blood group of the child. That is, it is possible for parents with blood group A and B to have a child with blood group O. In order to find out the blood group and genotype (genetic composition) of parents (both father and mother) students have to form hypothesis and design experiment to check hypothesis. They have to form hypothesis in such a way to check what are the different genotypes of parents can lead to child blood group as O. Once they form hypothesis they have to design experiments based on antigen-antibody reactions and confirm the genotypes.

The development of scientific reasoning skill has been the focus of a lot of research in science education research and it goes under different terms like inquiry learning, inquiry-based learning, scientific reasoning, mechanistic reasoning, science skill etc. Different teaching strategies like individual or collaborative learning are used in both face to face and online learning environment to develop scientific reasoning skill among students. Recent science education research has focused on the affordances provided by Technology Enhanced Learning (TEL) environments which help in facilitating collaborative learning, variable manipulation during experimentation, and immediate feedback to student responses.

In all such research, a key reasoning pattern that frequently occurs is hypothetico-deductive reasoning (Lawson, 2000) which includes formation of hypothesis to explain a phenomenon, checking of individual hypothesis by experimentation, designing of experiment, predicting the outcome based on experiment, collecting the observed outcome and matching predicted and observed outcome. Hypothetico-deductive reasoning is important in the understanding of many topics and domains in science. In the context of genetics, different causal explanations are possible for any observation which may be at different level of biological hierarchy. In order to identify the correct hypothesis this reasoning is required. This TEL environment is focussed on checking of individual hypothesis by designing experiment based on hypothesis chosen rather than generation of hypotheses. These hypotheses are generated on observed pattern given in the experimental observations. Students are able to accept or reject hypothesis based on whether predicted and observed result matches or not. In order to do that, they have to reason explicitly behind accepting or rejecting individual hypothesis.

The goal of this paper is to propose the design of a TEL environment, Geneticus Investigatio for hypothetico-deductive reasoning in the context of genetics education for undergraduates. While researchers have worked on the teaching-learning of hypothetico-deductive reasoning in biology (WISE, GO-LABS), most of these efforts are at the school level. Fewer efforts have been made at college level biology to address this reasoning skill especially in the context of genetics education. Secondly, this paper takes the approach of using the affordances of TEL environments to focus on students' ability to design experiments to test hypotheses. We have not encountered a TEL system that explicitly focuses on hypothetico-deductive reasoning for college level genetics so far.

What is Hypothetico-Deductive Reasoning (HDR)?

Hypothetico-deductive reasoning is a series of reasoning steps followed in order to explain any phenomena (Lawson, 2000). These steps are formation of hypothesis, checking of individual hypothesis by experimentation, designing of experiment, predicting the outcome based on experiment, collecting the observed outcome and matching predicted and observed outcome. Lawson (2000) proposed a sequence of steps (Figure 1) to implement the hypothetico-deductive reasoning process.

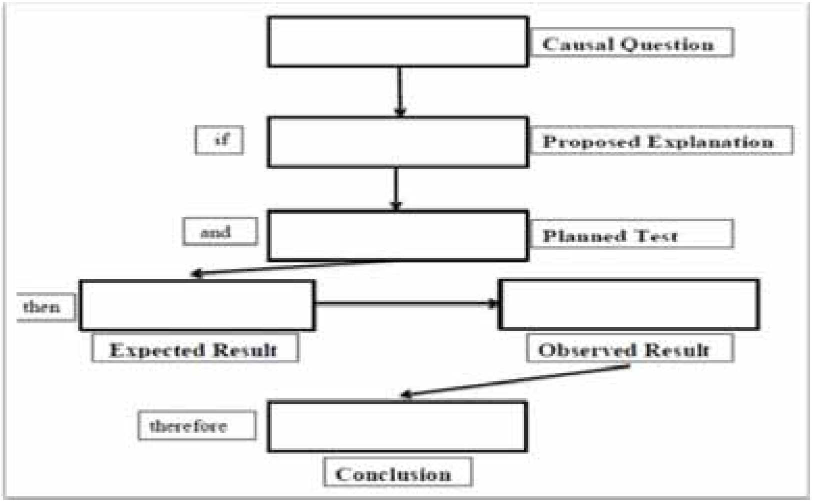


Figure 1: Sequence of steps as proposed by Lawson

Different steps of Lawson's flowchart actively engage students in the reasoning process. The first step of formation of hypothesis requires student to consider the context, For example, the scientific phenomenon to be explained. Students are first supposed to understand and describe context in their own words. In order to explain this context he/she forms different hypotheses. The generated hypotheses should be testable through experimentation i.e. students have to design an experiment to test considered hypothesis in the next step. Designing an experiment requires student to consider all dependent and independent variable (control of variables).This step requires synthesis of previous knowledge. Actual conduction of experiment requires sub-skills like proportional reasoning, co-relational reasoning and probabilistic reasoning. In this step student should be able to identify which independent variable to vary and what dependent characteristics to observe. Once the experiment is designed and results are collected, it has to be compared with the predicted outcome. If it is not supported then subsequent hypothesis is to be tested. This reasoning skill is related to Predict, Observe and Explain (POE) cycle (White & Gunstone 1992) but differs in the order in which some steps are carried out.

As an example consider the case of blood type alternate hypotheses for genotype of father and mother respectively are: (1) I^A I^A and I^B I^B, (2) I^A I^A and I^B i (3) I^A i and I^B I^B and (4) I^A i and I^B i

HDR is made explicit in the form of "If . . . and . . . then . . . And/But . . . Therefore . . . arguments."(Fig 1) An example to explain the hypothesis using these reasoning steps

If . . . I^A i and I^B i (chosen hypothesis)

and . . . the experiment is conducted as planned (planned test)

then . . . then one of the child can have O blood group (ii) (prediction)

and . . . one child have O blood group (ii) (result)

therefore . . . I^A i and I^B i hypothesis is supported (conclusion).

Hypothetico-deductive reasoning in genetics

Genetics is a branch of biology which connects different levels of biological hierarchy from molecular to sub-cellular to organismic level. In order to understand this connection scientific reasoning is important. Since different topics in genetics as given in "An introduction to genetic analysis" by Griffiths (2005) like pattern of inheritance, gene mapping have many competitive underlying reasons. In order to pin-point to the correct reason hypothetico-deductive reasoning process is required. An example from pattern of inheritance is in order to identify traits related to Mendel's pea plant which focuses on di-hybrid cross one has to perform cross breeding experiment with parent or offspring. It is done by matching experimental observations already known with actual observations through experimentation which is to be performed. Also in order to identify the correct locus and distance between genes in the genome in the process of gene mapping, this reasoning is required.

Hypothetico-deductive reasoning is fundamental to genetics and it is required in different context and for different target audience. For a researcher who is designing new experiment this reasoning skill is important otherwise he/she won't be able to do research independently, he/she will just do procedural activities. For a teacher who is teaching genetics to students it is important for them because he/she aims to develop this reasoning skill among student. Learning this skill in the context of genetics is also important because students of different biology domains like microbiology, botany, zoology, environmental biology etc. have to learn genetics as a part of compulsory course in curriculum.

Since hypothetico-deductive reasoning is important for developing scientific reasoning and for different target audience, our TEL system, Geneticus Investigatio will help them to improve this reasoning skill in its various steps through-out the system. Since Geneticus Investigatio makes each and every step of this reasoning skill explicit, allows for reflection and practice, provides opportunity for experimentation it will help these target audience as a supplement of traditional learning.

Literature Review

Science aims at understanding natural phenomena in as much detail and depth as possible. In order to do this scientific reasoning is important. This reasoning skill is made explicit in the form of hypothetico deductive reasoning, probabilistic reasoning, co-relational reasoning, and proportional reasoning (Koslowski, 1996; Zimmerman, 2000; Lawson, 2004). Students have difficulty in this reasoning and the difficulties are in the formation of hypothesis, designing of experiment, predicting the outcome of experiment (de Jong & van Joolingen, 1998). In order to address these difficulties, the teaching-learning of any concepts focus on inquiry-based learning. Inquiry-based learning is a student centred active learning approach focussed on critical thinking, questioning, and problem solving. Inquiry based environment can be guided or non-guided. In guided learning students are provided with immediate feedback which is considered more productive than non-guided learning (Alfieri et al., 2011). Mostly such feedback is in the form of scaffolds of different types: structural, reflective and subject matter (Fund, 2007). Scaffolds are also required in designing and actual conduction of the experiment. During designing of experiment student should be able to do variable manipulation through simulation (Blake & Scanlon, 2007) and observe result.

In the past two decades, technology enhanced learning environments have been used to provide the necessary instructional support, such as, guided prompts, self-paced learning, variable manipulation during experimentation and so on. Examples of such TEL environments to develop scientific reasoning include Go-Labs (Learning by Experience), Geniverse (Concord Consortium, 2010), Model-It (Jackson et al., 1996), AppleTree (Chen, et al., 2013) and WISE (Slotta, 2002). These environments are to be used either online or can be downloaded. Most of them focus upon junior and high school education. For example Go-Labs which is an online learning environment focusing upon guided experimentation. It has repository of 158 remote and virtual labs, 152 inquiry spaces and 34 apps for different subjects like physics, astronomy, chemistry, biology, geography, and math. Apple Tree focuses upon dual representational and interactional spaces, automated assessment for learning and staged-based collaboration scripts (Chen et al., 2013). In case of biology most of these learning environment focuses on concepts of ecology and evolution.

Design of Geneticus Investigatio

Learning objective

Hypothetico-deductive reasoning is defined as ability of formation of hypotheses, testing of hypothesis through experimentation, comparing predicted and observed result and revising hypothesis. By using Geneticus Investigatio students should be able to show Hypothetico-deductive reasoning. This reasoning is made explicit in different steps of Geneticus Investigatio. After interacting with Geneticus Investigatio , students should be able to:

- identify hypothesis which is to be tested through experimentation.

- design an experiment to test the hypothesis.
- write predicted outcome based on the designed experiment.
- run the experiment and collect result in terms of observed or measurable outcome.
- compare predicted and observed outcome and decide whether it matches or not.

Theoretical basis

Geneticus Investigatio is based on sequence of different steps followed during hypothetico-deductive reasoning as proposed by Lawson (2000). So, the system should allow students to make this reasoning explicit in the form of typed statements. It should also allow students to go back and forth between steps. Also, design of experiments requires different independent variables to be manipulated and dependent variable to be observed. These requirements suggests for TEL environment which can make these reasoning steps explicit. TEL environment makes students actively engaged in the learning activity. Designing of experiment is made explicit in simulation where student choose which independent value(s) to vary and what dependent characteristics to observe (Lee et al., 2002). It also provides students with immediate feedback based on their responses (Nicol & Macfarlane-Dick, 2006).This system allows student for self-paced learning.

Overall learning path

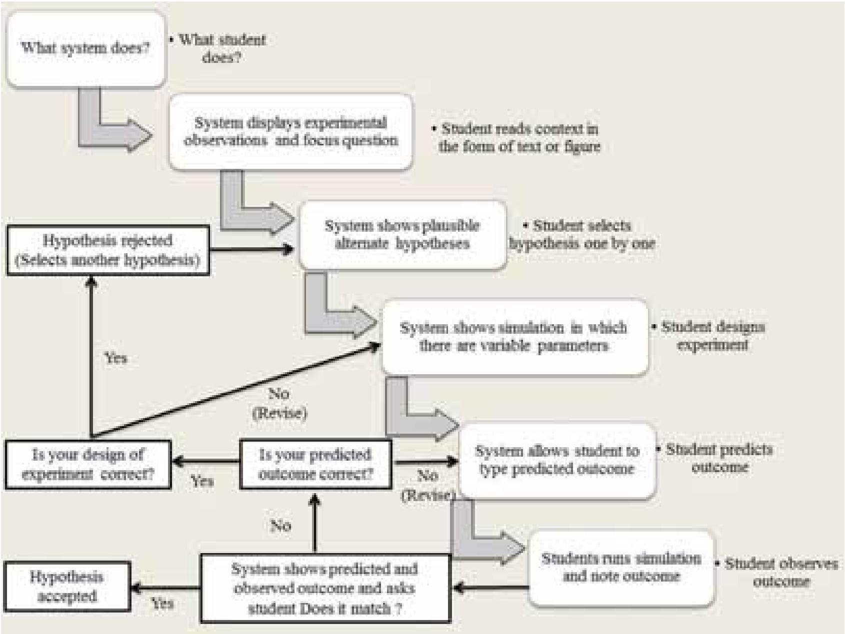


Figure 2: Overall learning path of Geneticus Investigatio

Design Elements

1. *Get familiar with the experimental observations:* Students are provided with experimental observations of phenomenon in the first interface. Students read the context and experimental observation. Separate experimental observations are included in different boxes (Fig 3).

2. *Choose hypothesis to be tested:* Students are shown different hypothesis which are to be tested. They have to select one hypothesis at a time which is to be tested in next stage of design of experiment (Fig 4).
3. *Design of experiment:* Student have to propose the design of their experiment in the given text box. At this point they will be able to see the simulation interface where they can perform the experiment. They can see which variables can be manipulated and based on that they have to design their experiment (Fig 5). At this point they won't be able to run experiment. If they want hint they can click the tab and ask for hint which will help them to identify the dependent and independent variable. In the next tab students are asked to write the predicted outcome based on the designed experiment (Fig 6).They have to type their response within the box. Once they click submit button then run button appears on the same interface where they can perform the experiment based on the designed experiment (Fig 7).
4. *Comparison of predicted and observed result:* They see the hypothesis which was chosen, design of the experiment, predicted outcome and type the observed result. While writing observed result student will be able to draw diagram and do calculations. Then they are asked whether predicted and observed outcome matches or not (Fig 8). If they say yes then hypothesis considered is accepted.
5. *Feedback and scaffolds:* Feedback and scaffolds are provided at different steps in the system. Once during the design of the system where they have to choose dependent and independent variable another after comparison of predicted and observed result. The system asks students is predicted outcome correct and if incorrect revise the predicted outcome? If predicted outcome is correct system asks student to reconsider the design of the experiment. If the design of the experiment is incorrect then student have to revise design of experiment. If it is correct then hypothesis is rejected and another hypothesis is considered for testing.

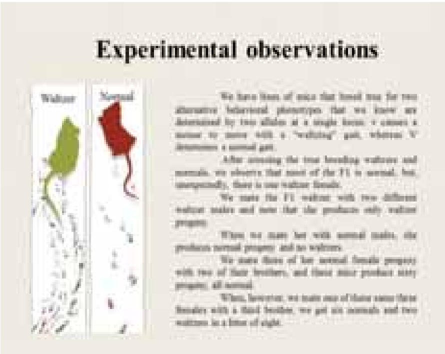


Figure 3: Know the experimental observation

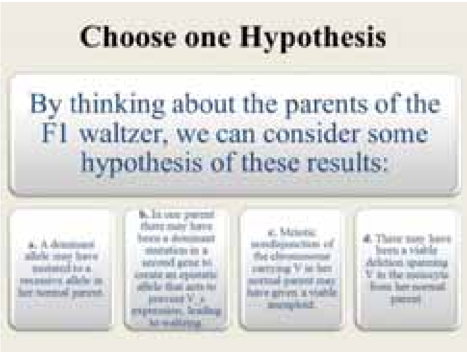


Figure 4: Choose hypothesis for testing

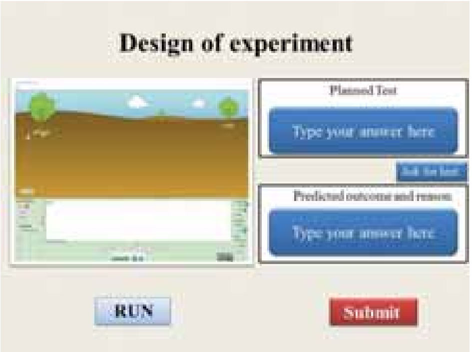


Figure 5: Write planned test

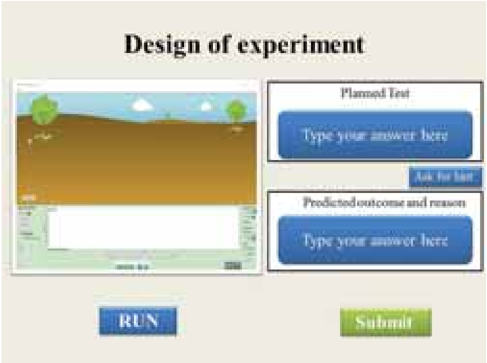
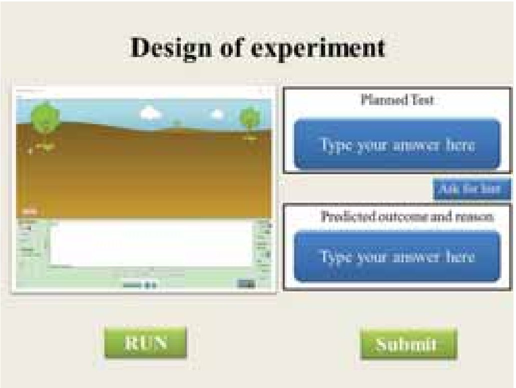


Figure 6: Write predicted outcome



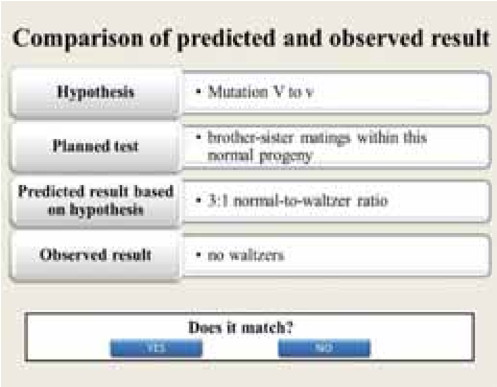


Figure 7: Design of experiment

Figure 8: Comparison of predicted & observed result

Proposed Method

Design Based Research (DBR) focus on creation and analysis new solution of identified problem. As proposed by Reeves in 2006 (Fig 9) it includes four different steps and iterations between these steps.

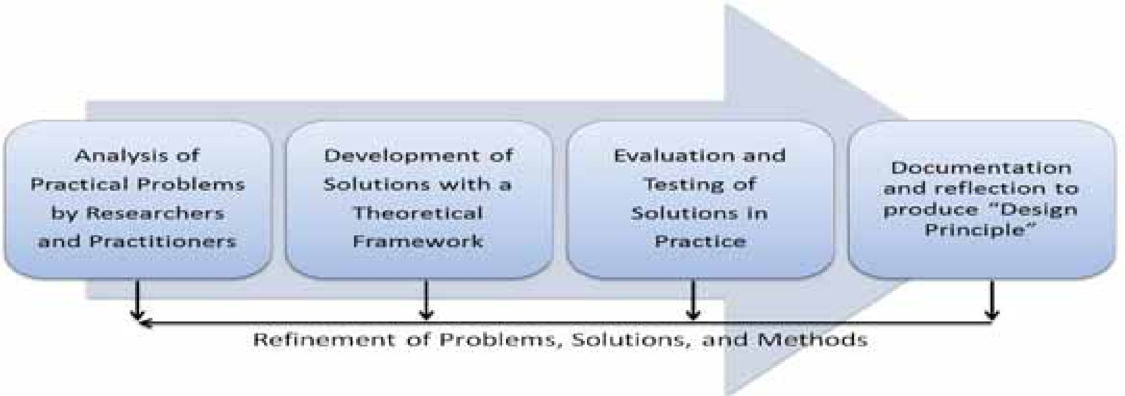


Figure 9: Steps of design based research approach (Reeves, 2006)

In the first step of identification of practical problem by researchers and practitioners problem in hypothetico-deductive reasoning was identified which was also supported through literature. It includes problems faced by students in different steps of hypothetico-deductive reasoning. In order to solve this problem Geneticus Investigatio is designed in which different steps were proposed which has theoretical basis like explicit writing of predicted and observed outcome, immediate feedback, self-paced learning and revision based on reflection.

In the next step of evaluation and testing of solution Geneticus Investigatio will be implemented with first year undergraduate biology student. Implementation will include measurement of learning outcome (pre-post difference) study with Geneticus Investigatio as intervention. Questions in tests will focus on assessment of scientific reasoning. Students will be asked to participate in system usability survey and interview will be taken about feedback on interaction with Geneticus Investigatio. Based on feedback user interface changes will be incorporated in the next cycle of DBR. Also it would be interesting to do a co-relational study with number of iteration of reasoning activities and its effect on students' development of HDR skill.

SUMMARY

Geneticus Investigatio is a technology enhanced learning environment that aims to develop HDR skill in undergraduate students. This paper describes the importance of this skill and problem faced by students in the context of genetics education. Different steps of this environment is based on affordances provided by TEL environment like variable manipulation in simulation, self-paced learning, immediate feedback, reflection and revision and an opportunity for experimentation. Future work aims at next step of DBR cycle in which Geneticus Investigatio is to be implemented with undergraduate students and study on learning and perception of student is to be done.

References

Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *Educational Psychology Review*, *103*(1), 1–18.

Blake, C., & Scanlon, E. (2007). Reconsidering simulations in science education at a distance: features of effective use. *Journal of Computer Assisted Learning*, *23*(6), 491-502.

Chen, W., Looi, C., Xie, W., & Wen, Y. (2013). Empowering argumentation in the science classroom with a complex CSCL environment. In S. C., Tan et al. (Eds.), *Proceedings of the 21st International Conference on Computers in Education.* Indonesia: Asia-Pacific Society for Computers in Education.

Concord Consortium. (2010). Geniverse (Accessed: 13 Oct. 2015). *Geniverse* [Online]. Available: https://concord.org/projects/geniverse

De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, *68*(2), 179-201.

Fund, Z. (2007). The effects of scaffolded computerized science problem-solving on achievement outcomes: a comparative study of support programs. *Journal of Computer Assisted Learning, 23*(5), 410–424.

Griffiths, A. J. (2005). *An introduction to genetic analysis*. Macmillan.

Jackson, S. L., Stratford, S. J., Krajcik, J. S., & Soloway, E. (1996). *Model-It: A case study of learner-centered software design for supporting model building.* Arlington, VA: National Science Foundation.

Koslowski, B. (1996). *Theory and evidence: The development of scientific reasoning.* MA: Mit Press.

Lawson, A. E. (2000). The generality of hypothetico-deductive reasoning: Making scientific thinking explicit. *The American Biology Teacher*, *62*(7), 482-495.

Lawson, A. E. (2004). The nature and development of scientific reasoning: A synthetic view. *International Journal of Science and Mathematics Education*, *2*(3), 307-338.

Lee, A. T., Hairston, R. V., Thames, R., Lawrence, T., & Herron, S. S. (2002). Using a computer simulation to teach science process skills to college biology and elementary education majors. *Computer Simulations Bioscene*, *28*(4), 35-42.

Learning by Experience G0-LAB (Accessed: 13 Oct. 2015). GO-LAB [Online] Available: http://www.go-lab-project.eu/

Nicol, D. J., & Macfarlane Dick, D. (2006). Formative assessment and self regulated learning: a model and seven principles of good feedback practice. *Studies in Higher Education, 31*(2), 199-218.

Reeves, T. C. (2006). Design research from a technology perspective. *Educational Design Research*, *1*(3), 52-66.

Slotta, J. (2002). Designing the "Web-based inquiry science environment (WISE)." *Educational Technology*, *42*(5), 15-20.

White, R., & Gunstone, R. (1992). *Probing understanding.* London and New York: The Falmer Press.

Zimmerman, C. (2000). The development of scientific reasoning skills. *Developmental Review*, *20*(1), 99-149.