

Theoretical Foundations of Developing Modeling Instruction Curriculum for College Biology Courses

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Abstract: Modeling instruction has been successfully implemented in high school science classes and in introductory physics courses at the university level. Noticing the gap, the author provides theoretical foundations to support the statement that modeling instruction curriculum should be developed for college biology courses.

It has been over a decade that college biology faculty, administrators, and students demanded for improving university biology education (Wood, 2009; Woodin, Smith, & Allen, 2009). Current studies on biology education pay too much attention merely on the improvement in students' concept acquisition and/or academic grades. However, learning motivation (particular intrinsic motivation) is often overlooked, which plays a key role in initiating and retaining good learning habits (Palmer, 2005) and in promoting achievements. Intrinsic learning motivation, besides conceptual understanding, can be one of the characteristics that distinguish experts from novices. The intrinsic motivation in learning biology stimulates individuals to acquire more biological concepts and perform higher level of biological practices. Experts with high intrinsic motivation in learning biology tend to understand biology as connections of coherent concepts and seek solutions to emerging problems. If a student has no or not enough motivation to learn, he or she is not inspired to act (Ryan & Deci, 2000). Therefore, studies on motivation can contribute to the improvement of curriculum in university biology education. Significant research attention needs to be paid to examine students' cognitive attitudes, motivation, expectations, views, and epistemological beliefs, all of which begin to link with concept learning and academic performance in introductory level biology courses. Taking the factors above into consideration, biology educators should use more effective instructional strategies to enhance undergraduate students' motivation as an essence.

Early in 2001, the American Association for the Advancement of Science identified developing, implementing, and evaluating scientific models as one of the six essential student competencies to reform college biology education (Brewer & Smith, 2011). Since then, considerable studies on models and modeling in biology education have been conducted; however, it is still pending on what models are, what constitutes the practice of modeling, and how to improve modeling skills while delivering content knowledge (Odenbaugh, 2009; Stewart, Cartier, & Passmore, 2005; Windschitl, Thompson, & Braaten, 2008). Modeling instruction (MI) can be one of the leading educational practices in university-level biology education, which can enhance undergraduate students' intrinsic motivation and fill the existing gap that MI curriculum is missing in college-level biology classes.

Modelling Instruction

From the MI perspective, teaching practice is designed and organized to engage students with specific concepts or topics, in developing models, and applying and assessing models in real life situations (Jackson, Dukerich, & Hestenes, 2008). First, a teacher demonstrates or discusses a specific concept or topic with students to build a basic understanding of it. Then students work collaboratively in small groups to model the real life question in an experimental setting to

predict and explain the scientific phenomenon. The teacher, with enough knowledge in a certain field, is ready to answer students' questions, guide their model developing, and evaluate their models. Through MI, the understanding of specific concepts is integrated into students' real hands-on practice, which may promote their understanding of knowledge and help them connect scientific concepts with real life (Jackson et al., 2008).

MI in College Physics Education

The application of MI in physics education has been well studied and practiced for decades and has been reported on its positive effects on undergraduate students' learning in introductory physics courses (Brewer, 2008; Brewer, Kramer, & O'Brien, 2009; Hestenes, 1987). Brewer et al. (2009), measuring with Colorado Learning Attitudes about Science Survey (CLASS), found that MI had a positive effect on students' attitudes towards introductory physics.

Current Gap of MI in College Biology Education

As to biology education, MI has been applied in biology teaching in high schools (Cartier, 2000; Passmore & Stewart, 2002). With this instructional strategy, students are encouraged and directed to design, build, and evaluate scientific models to predict and/or explain a biological phenomenon according to related concepts. Through the process of instructional modeling, activities of biological practices are conducted and replicated in classrooms or teaching labs so that the explicit nature of biological themes in curriculum is integrated and transferred to students. However, the university biology MI materials are still under development, and the effectiveness of MI in biology education in universities is yet to be examined.

Given the gap in research studies and practices of MI in university-level biology education, this paper aims to establish a theoretical foundation to support the development and evaluation of MI curriculum for university biology courses.

Connections of MI and Social Cognitive Theory

MI emphasizes and values the importance of learning environments (Jackson et al., 2008), which is the essence of social cognitive theory (Schunk, 2000), in science education. It provides students chances to collaborate and interact with group members in a small group to complete a project, through which students can learn from each other. Students with lower self-efficacy and/or fewer skills can be motivated to perform better after observing and modeling the performances and achievements of peers with higher self-efficacy and/or more skills. The atmosphere of autonomy in MI groups allows students to determine by themselves in how to design, plan, and conduct a specific project, which increases their intrinsic motivation in learning associated concepts from the project.

Social Cognitive Theory

Social cognitive theory (SCT) is based on the idea that people learn by observing others (Schunk, 2000). People learn portions of their knowledge directly from their social environments by observing others in social interactions, social experiences, and media content. People learn by observing behaviors of models, and those models provide information to learners about potential consequences of behaviors. Learners observe, pair, and remember behaviors and associated consequences and then guide their own subsequent behaviors accordingly. People retain observed behaviors that lead to successful consequences and refine or avoid behaviors that result in failure and/or punishment (Schunk, 2000).

Self-Efficacy

Within the SCT framework, it is assumed that, if an observer (learner) has enough self-efficacy, he or she will most likely learn the knowledge. Self-efficacy refers to the personal belief of an individual about whether he or she has mastered particular capabilities to learn or

perform certain actions (Bandura, 1997). It is people's personal assessment and belief of their own skills and capabilities to apply those skills to real performance. Lent and Brown (2006) described self-efficacy as a series of dynamic beliefs, rather than a single characteristic, of an individual that are context-dependent. Self-efficacy partially relies on individuals' abilities. That is to say, in general, people with higher abilities tend to have higher self-efficacy in learning and acting than those with lower abilities. However, self-efficacy is not ability. People with higher self-efficacy are more active in learning and completing tasks, tend to put more effort, and persist longer time than people with lower self-efficacy, which, in turn, improves their learning achievements. People with high self-efficacy are more likely to be motivated to complete tasks. Therefore, even if in the same level of capabilities, people with higher self-efficacy are usually more active and perform better than those with lower self-efficacy.

People acquire information about their efficacies through their own mastery experiences, observing others' performances, persuasion from others, and physiological factors. According to Bandura (1997), an individual acquires his or her self-efficacy primarily from personal mastery experiences. Successful experiences in completing a task may positively influence one's self-efficacy in completing a similar task (Bandura, 1997). The second source of self-efficacy, vicarious learning experiences, is particularly important when one has no personal experience with the task at hand or similar ones (Bandura, 1997; Zeldin & Pajares, 2000). VL refers to an individual observing someone else performing a similar task. Others' success on a task may influence the observer's self-efficacy in performing the similar task. Social persuasion experiences such as encouraging words or positive social messages, as the third source, may promote one's self-efficacy and make this person to put extra effort and persistence to complete a task. Bandura (1997) argued that SP has highest influence on those already with beliefs about their ability to complete a task.

Empirical Studies of Self-Efficacy

Pajares (1995) reported that self-efficacy affected behaviors by regulating one's choices of performance, the extent of one's effort in performing specific actions, and one's affective responses to certain behaviors. Based on self-efficacy theory, Ketelhut (2007) conducted an exploratory investigation on the relationship between students' longitudinal data-gathering behaviors and their self-efficacy when participating in an authentic scientific inquiry-based activity in a multi-user virtual environment. Results of this study indicated a correlation between students' self-efficacy and the amount of data-gathering behaviors they initially engaged in. Students with higher self-efficacy engaged in more data-gathering behaviors than those with lower self-efficacy. Findings in this study suggested that embedding collaborative scientific inquiry-based curriculum project in science teaching might promote students' self-efficacy and learning outcomes.

Hazari, Sonnert, Sadler, and Shanahan (2010) reported that self-efficacy contributed to students' retention in physics as one of the primary dimensions of their physics identity. Further, Sawtelle, Brew, and Kramer (2012) conducted a quantitative study investigating the relationship of undergraduate students' self-efficacy and their retention in the Introductory Physics course. This study applied self-efficacy theory to explain the difference between female and male students in persistence in the introductory physics course. The authors discussed four sources of an individual's self-efficacy: mastery experiences, vicarious learning experiences, social persuasion experiences, and physiological state. They proposed self-efficacy theory as the framework to explore the sources of information that female students perceive and rely on to determine their capabilities to success in physics (Sawtelle et al., 2012), which was supported by

the evidence from previous studies of Zeldin and Pajares (2000) and Zeldin, Britner, and Pajares (2008) showing gender difference in students' self-efficacy sources in science learning. Sawtelle et al. examined the self-efficacy of students in the introductory physics classes to explore the gender difference in the sources of self-efficacy with regard to their persistence in physics. Results suggested delicate distinctions by gender in the predictive capabilities of the sources of self-efficacy regarding to students' success in physics. The predictive capability for women's success in physics primarily relies on vicarious learning experiences, while no significant contribution from social persuasion experiences. The predictive capability for men's success in physics only relies on mastery experiences.

Self-Determination and Autonomous Learning Environment

Self-determination and autonomous learning environment is another critical characteristic of MI. It originates in infants and is people's internal psychological need that, if satisfied, leads to optimal intrinsic motivation (Deci & Ryan, 1991). Along with human development, the need differentiates into various areas, which is influenced by people's interactions with environments (Schunk, 2000). Many extrinsic rewards in social environment may not originally fit with an individual's need for self-determination, but they can stimulate good behaviors. As people develop, these extrinsic motivators may be internalized and produce intrinsic motivators through self-determination. Self-determination theory suggests that the motivated degree of behaviors differs depending on whether they are autonomous or controlled. Deci and Ryan (1991) argued that autonomous behaviors are developed originally from an individual's integrated sense of self. Controlled behaviors can be internalized to become autonomous, in which an individual identifies the value of specific behavior and accepts its regulation as one's own. The degree of an individual's behaviors are autonomous or controlled is influenced by the interpersonal context. By autonomy support, the teacher, as a person in authority, thinks from students' perspectives, takes their feelings into consideration, and provides them with enough relevant information and chances to determine and select by themselves, while avoiding or at least minimizing the use of pressure (Deci & Ryan, 1985). Autonomy support facilitates in maintaining or improving intrinsic motivation and enhancing internalization of external regulation into internal regulation.

Empirical Studies of Self-Determination and Autonomous Learning Environment

Deci, Schwartz, Sheinman, and Ryan (1981) reported that students, autonomy-supported by their teachers, were more intrinsically motivated. Students in autonomy-supportive context, according to the research findings of Grolnick and Ryan (1987), had better conceptual acquisition. The study of Black and Deci (2000) examined the effects of students' course-specific self-regulation and their perceptions of instructors' autonomy support on students' adjustment and academic performances in an undergraduate organic chemistry course. Results indicated that students' autonomous reasons for learning organic chemistry predicted their perceived competence, interest/enjoyment, anxiety, and grade-oriented performance in the organic chemistry course and were also related to students' dropping out of this course. Students' perceptions of their instructors' autonomy support predicted their autonomous self-regulation, perceived competence, interest/enjoyment, and anxiety. Students' autonomous self-regulation further predicted students' performance in the organic chemistry course. Furthermore, instructor's autonomy support from students' perceptions also directly predicted course performance of students with low level of initial autonomous self-regulation.

Deci and Ryan (1985, 1991) argued that motivation can be classified along with the level of self-determination, according to which intrinsic motivation is the most self-determined one and extrinsic motivation is the least self-determined one. Lavigne, Vallerand, and Miquelon

(2007) proposed and examined a motivational model of persistence in science education, which is supported by self-determination theory. This model hypothesized that the autonomy support from science teachers positively influences students' self-perceptions of autonomy and competence, and that these self-perceptions further positively affect students' autonomous motivation towards science, which leads to their intentions to pursue science education and eventually work in a scientific area. Cognitive evaluation theory was also applied in this study, which suggests that social agents, such as teachers, may affect one's motivation through autonomy support. The proposed model is supported by the results from this study. In addition, it was found that students' perceptions of competence predicted their persistence intentions to pursue science education. Findings in this study direct future research in science education from a motivational perspective.

Connections of MI and Constructivism

In teaching practice, MI involves and promotes constructivist learning. Through MI, students learn scientific concepts by really experiencing them in working collaboratively to model them in their real process to utilize specific concepts to explain and predict scientific phenomena. During MI process, students construct scientific knowledge internally by interacting with real science experiences, cooperative peers, and the teacher. The research study findings (Amaral, Garrison, & Klentschy, 2002; Park Rogers & Abell, 2008) particularly support the application of inquiry-based science teaching curriculum, which is one of the aspects of MI.

Constructivism

Constructivism assumes that people are active learners and that knowledge is not acquired automatically but constructed by learners via its interaction with learners' experiences and perceptions of new information. Constructivism underlies integrated curriculum, which support students learning a topic in various ways. According to constructivism, teaching, rather than a simple delivery of knowledge to learners, is to provide materials and instruction to help students involved in active learning through social interactions with materials, peers, and the teacher. Those active learning activities include generating learning goal, monitoring and assessing learning process, observing, and working collaboratively with peers (Schunk, 2000). Individuals construct new knowledge from interactions between one's mental framework and experienced environments.

From a constructivist perspective, teaching is to help students investigate and resolve conflict in their experiences (Sandoval, 1995). In science education, it is to help students identify and correct misconceptions (Mayer, 1999). It engages students in hands-on activities and collaboration with others to solve proposed problems through their experiences. Students come to class with their own personal pre-constructed scientific concepts. Thus, according to the constructivist perspective in science education, teachers could first know and understand students' scientific preconceptions, then identify conceptual conflict with their preconceptions, and finally help them to explore and modify their scientific conceptions (Nussbaum & Novick, 1982). Teachers can associate hands-on experiences in science with students' real life to promote their interest and motivation in learning science. According to Vygotsky's sociocultural theory (Vygotsky, 1978), learning is a socially mediated process, and people learn through interaction with others. As to the teaching practice, teacher should provide rich real experiences to encourage students to learn.

Empirical Studies of Constructive Teaching in Science Classes

Paris and Turner (1994) found that engaging students in hands-on biology activities improved their intrinsic motivation and self-regulation learning behaviors. Paris, Yambor, and

Packard (1998) investigated the effects of an extracurricular hands-on curriculum and instruction in biology on students' interest and learning achievements. Students' both interest in science and problem-solving skills through all grade levels were increased. Female students reported more positive attitudes towards science and higher problem-solving skills than male students did. Data from qualitative interviews with three teachers supported the benefits of the hands-on biology curriculum and instruction.

Stohr-Hunt (1996) conducted a variance analysis of the relation between the frequency of students experiencing hands-on science and their science achievements. Data were collected by the National Education Longitudinal Study of 1988 on a nationally representative sample of eighth-grade students. Students who engaged in hands-on activities every day or once a week scored significantly higher on a standardized test of science achievement than those who engaged in hands-on activities once a month, less than once a month, or never.

Amaral, Garrison, and Klentschy (2002) reported the findings of a four-year project in science education with English learners in grades K–6. Participating students' achievements in science, writing, reading, and mathematics were measured and analyzed according to the number of years that students participated in the inquiry-based science education program. The English learners' achievements correlated with the number of years they were engaged in the program. The longer they were in the program, the higher they scored in science, writing, reading, and mathematics.

Concluding Thoughts for Future Discussion

MI engages students collaboratively and autonomously in real hands-on inquiry-based scientific activities to develop and use models to describe, explain, and predict scientific phenomena. As a practical application of SCT, MI could enhance students' self-efficacy in science learning, which could promote students' learning motivation, rewarding learning behaviors, persistence in science learning, and further improve their academic achievements. It could also, through autonomy support, improve students' learning motivation and attitudes and further improve their academic persistence in science. In addition, MI could promote students' interests and academic achievements in science by providing real hands-on experiences and stimulating constructivist learning. With its inquiry-based characteristics, MI can enhance interests and motivations of both science and non-science major undergraduate students. MI may even benefit English learners in their science achievements as an inquiry-based science teaching strategy. MI may also contribute to the diminishing of gender gap in college biology education.

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