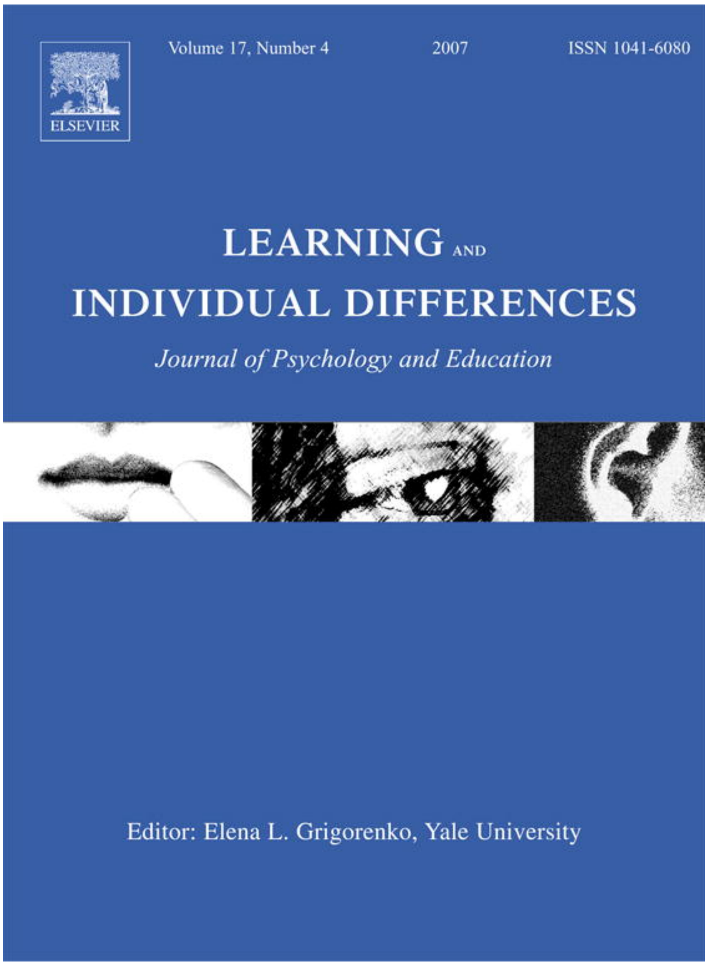
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The interplay between cognitive and motivational variables in a problem-based learning environment

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Abstract

Problem-based learning (PBL) is a student centered approach whereby students deal with ill-structured problems while working in small groups. In this study, a path model was utilized to model the relationships among reasoning ability, learning approach, prior knowledge, motivational variables, and achievement in genetics in PBL classes. 126 eighth grade students participated in the study. Results showed that reasoning ability, learning approach, task value, and prior knowledge had direct effects on achievement in genetics. Moreover, reasoning ability and task value were found to have indirect effects which were mediated by learning approach. Interrelationships found among the variables in the path model were discussed considering the characteristics of the PBL environments and suggestions were made for further research.

Keywords: Problem-based learning; Path analysis; Achievement

1. Introduction

One of the primary goals of research in education and educational psychology is to help students apply scientific concepts to real life problems (Chin & Chia, 2006). According to Ausubel (1968), such meaningful learning is encouraged whenever students relate new knowledge to relevant concepts they already know. For meaningful learning to take place, however, students should not acquire isolated facts; they should construct new knowledge by drawing relationships among several different concepts, both new and old. Meaningful learning is also associated with a deep learning approach (Entwistle & Ramsden, 1983), which refers to an intention to understand the material. The predominant strategies of this approach are use of evidence and the relating of different ideas, and its predominant motive is an interest in the ideas presented (Diseth, Pallesen, Hovland, & Larsen, 2006). Entwistle and Ramsden (1983) reported that students who adopt a deep learning approach are likely to find the task more interesting and easier to understand. In general, a deep approach is found to be associated with a deep level of understanding.

In contrast, the surface approach to learning involves rote memorization. In this approach, the student's intention is to meet the minimum course requirements and their external motive is to avoid failure by simple recall (Diseth et al.,

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2006). Cavallo, Potter, and Rozman (2004) suggested that the surface approach to learning is not sufficient to achieve a sound understanding of scientific concepts. Cavallo (1992) found a significant positive relationship between the depth of a student's approach to learning, their prior knowledge, and their level of meaningful understanding after completing a genetics course. In a similar study, Cavallo (1996) later reported that a deep approach to learning is the best predictor of meaningful understanding. On the other hand, students relying on the surface approach appeared to need help in applying the concepts, indicating a lack of meaningful understanding.

The surface approach to learning is associated with extrinsic motivation, while the deep approach to learning is related to intrinsic motivation (Entwistle & Ramsden, 1983). Students with higher levels of intrinsic motivation to academic achievement are more likely to attain meaningful understanding. In fact, educational research has long since shown that there is a positive relationship between intrinsic motivation and the use of learning strategies that lead to meaningful understanding (Al-Ansari, 2005; Meece, Blumenfeld, & Hoyle, 1988; Neber & Schommer-Aikins, 2002; Pintich & DeGroot, 1990; Tung-hsien, 2004; Valle et al., 2003).

Motivational variables which have been found to be strongly related to learning strategy include self-efficacy, control of learning beliefs, task value, and intrinsic goal orientation (Pintrich, 1999; Pintich & DeGroot, 1990; Pintrich & Schunk, 2002). Self-efficacy involves one's perceived ability to learn or perform effectively, while control of learning beliefs refers to the expectation that a positive learning outcome will result from personal effort. Both experimental and correlational studies have shown that both of these factors in a student's self-judgment are positively associated with desired schooling outcomes such as persistence, cognitive engagement, the use of strategies essential to meaningful learning, and actual achievement (Buehl & Alexander, 2001; Linnenbrink & Pintrich, 2002). In addition, studies have demonstrated that a student's task value (which refers both to the perceived importance and utility of the task and to the student's interest in it) is also associated with the use of deep learning strategies and better academic achievement (Pintrich & Schunk, 2002). Finally, students with an intrinsic goal orientation (see below) were found to use deeper learning strategies and perform better on academic tasks (Eccles & Wigfield, 2002; Pintich & DeGroot, 1990; Pintrich & Schunk, 2002; VanderStoep, Pintrich, & Fagerlin, 1996; Zimmerman, 2000).

Students with intrinsic goal orientation engage themselves in the task of learning and understanding. The relevant literature has shown, however, that one of the factors affecting goal orientation is the students' perceived control over their learning (Valle et al., 2003). For instance, students who believe that their ability to learn can be improved through effort tend to have intrinsic goal orientation. In line with these results, it is to be expected that self-efficacy, task value, control of learning beliefs, and intrinsic goal orientation are all related to student achievement and their adopted learning approach in the subject of genetics (and by extension other sciences). Moreover, it can be predicted that these motivational variables are all related to each other.

Since the study of genetics requires a high level of abstract thinking, however, learning orientation and motivation may not be sufficient to explain the observed variations in achievement. It is essential to consider the students' native reasoning abilities as well. Many studies have shown that reasoning ability is also a strong predictor of achievement for several biological concepts, including genetics (Cavallo, 1996; Johnson & Lawson, 1998; Lawson & Thompson, 1988).

In today's world, one of the major goals of science education is to encourage the development of scientific thinking in students. This can be accomplished by creating a rich, problem-based learning (PBL) environment, where students are given inquiry-based tasks that require the same cognitive processes used by scientists. Chin and Chia (2006) suggested that scientific thinking can be developed by integrating PBL into the curriculum. There is thus a need to investigate the relationships between cognitive ability, motivational variables, and achievement in such environments. Specifically, the present study is aimed at modeling the relationship between achievement in a genetics course, learning approach, prior knowledge, motivational variables, and reasoning ability. The proposed structure of the model is summarized in Fig. 1, and is based on the null assumption that all the relationships shown are independent of the learning environment. Therefore, relationships which had already been established by earlier studies were used to construct the initial model.

2. Methods

2.1. Sample

The subjects of the study were 126 eighth-grade students, attending four intact classes in an urban middle school. The sample included 60 boys and 66 girls, aged between 13 and 15 years. The majority of students came from a middle class background.

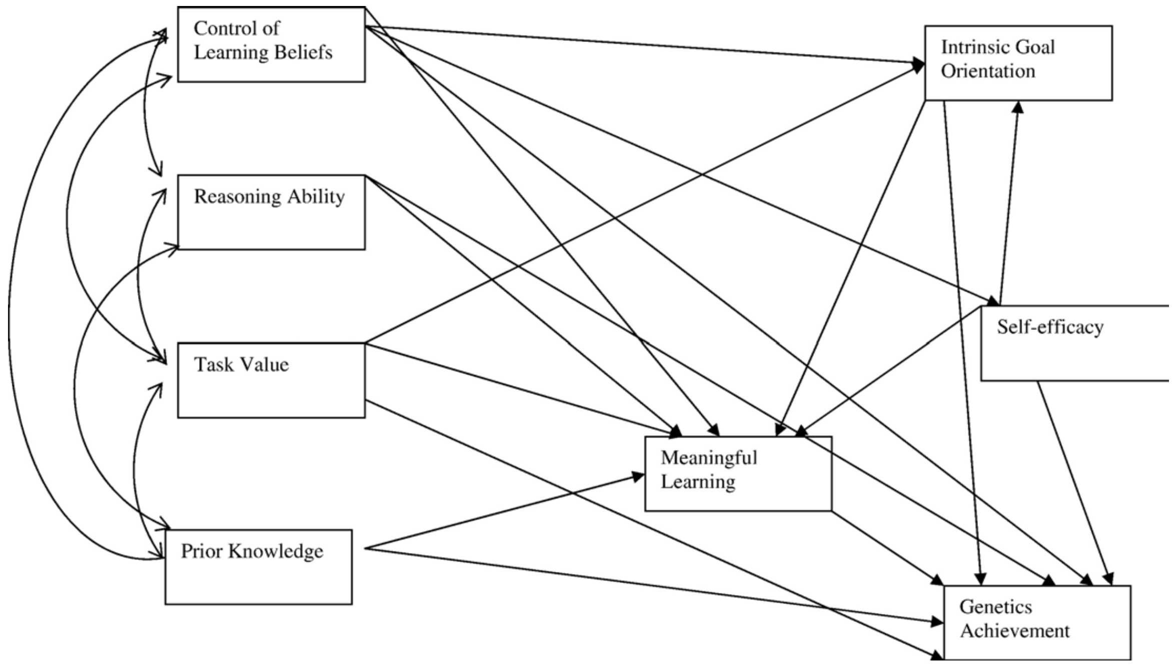

Fig. 1. Conceptual model.

2.2. Instruments

The Test of Logical Thinking (TOLT), developed by Tobin and Capie (1981), was used to measure the formal reasoning ability of the students. The test consists of 10 items. Students respond to each item by selecting a response and also their reason for selecting that response. For an item to be scored correct, the student must check both the best answer and the best justification. TOLT scores range from 0 to 10. The internal consistency reliability coefficient of the test was found to be 0.85.

The Learning Approach Questionnaire (LAQ), a 22-item instrument, was used to measure each student's approach to learning on a scale ranging from deep (meaningful) to surface (rote) (Cavallo, 1996). Students responded to each item on a four-point Likert scale consisting of "always true" (4 points), "more true than untrue" (3 points), "more untrue than true" (2 points), and "never true" (1 point). The scores obtained therefore range from 88 to 22. The alpha coefficient for the whole scale was found to be 0.60.

The Motivated Strategies for Learning Questionnaire (MSLQ), developed by Pintrich, Smith, Garcia and McKeachie (1991), was used to measure the students' motivational beliefs. The MSLQ is an 81-item self-reporting instrument in two sections: one on motivations and the other on learning strategies. The motivation section consists of 31 items in six categories (subscales). In this study, only four of the subscales in the motivation section (intrinsic goal orientation, task value, control of learning beliefs, and self-efficacy for learning and performance) were used to measure the students' motivational beliefs. The responses were scored on a 7-point Likert scale, where 1 point was given to "not at all true of me" and 7 points were given to "very true of me". The scores for each subscale were determined by adding up all items and taking the average. Subscale reliabilities ranged from 0.68 to 0.93.

The Genetics Achievement Test (GAT). The GAT was used to measure the students' achievement in the genetics course unit. This was a 20-item multiple-choice test developed by the researchers. Items in the test were related to Mendelian Genetics. The content of each item was validated by a group of experts in biology, biology education, and measurement and evaluation. The classroom teachers also analyzed the relevance of each test item to the instructional objectives. The GAT was administered twice, once to measure prior knowledge and again to measure achievement in genetics after the course unit. The internal consistency of the test was found by calculating Cronbach's alpha, which gave $r=0.63$ for this sample.

2.3. PBL implementation

In PBL classes, students are introduced to complex, ill-structured problems with no obvious solutions. The problems were posed as cases from real life related to monohybrid crosses and genetic diseases. Case information was distributed

Table 1
Descriptive statistics with respect to motivational and cognitive variables

Variables	*M*	SD	Skewness	Kurtosis
Intrinsic goal orientation	5.43	1.14	−.77	.41
Task value beliefs	5.39	1.08	−.80	.68
Control of learning beliefs	5.80	1.13	−1.11	.33
Self-efficacy for learning and performance	5.08	1.16	−.55	−.15
Reasoning ability	2.02	2.06	1.23	1.00
Meaningful learning orientation	57.18	4.16	−.20	.17
Prior knowledge	6.40	3.32	.55	−.17
Genetics achievement	11.22	3.35	−.12	−.47

over several pages, and were presented one by one. For example, in a case related to sickle cell anemia the students were given the patient's age, gender, major complaints, and a few other minor facts. Students worked in small, heterogeneous groups to identify what additional information they needed based on the initially given facts. They then brainstormed ideas and hypotheses related to the problem, decided on the key issues, and identified the resources to be used. Case information in the following pages included further information on the patient's history, symptoms, results of laboratory tests, diagnosis, and treatment. These pages were distributed by the teacher over the given time period, according to student requests. This approach allowed students to revise their ideas as work progressed.

After class, each student conducted an independent search for information regarding issues related to the problem. Students shared this information with their group, which could then discuss the case in light of new knowledge and possibly revise their hypothesis again. The process of research and group discussion continued until all groups were satisfied that they had learned sufficient basic science to solve the problem. Throughout the process, the teachers monitored and facilitated group activities and provided formative feedback.

3. Result

3.1. Preliminary analysis

Statistical Package for Social Sciences (SPSS) (version 10) was used to analyze all the descriptive statistics presented below. The mean, standard deviation, skewness, and kurtosis of each variable in the model are displayed in Table 1. Examination of the skewness and kurtosis values indicates that a normal distribution could be assumed for all of the observed variables.

3.2. Path analysis

A path analysis of the conceptual model was conducted using the LISREL 8.30 program and the SIMPLIS programming language. The goodness of fit measures presented in Table 2 indicate that the initial conceptual model (based on previously published relationships) did not fit the data very well. Based on these preliminary results, modifications were made and a new model was specified. All non-significant paths were eliminated, and one additional pathway was hypothesized leading from prior knowledge to intrinsic goal orientation (see Fig. 2). As shown in Table 2, the re-specified model results in an acceptable fit.

Since the goodness of fit indices for the re-specified model provide evidence that the second model is an adequate fit to the data, standardized path coefficients for the direct, indirect, and total effects of each factor were calculated. The results of this analysis are presented in Table 3, and standardized path coefficients for the direct effects are graphically displayed in Fig. 2.

Table 2
Measures of model fit

Model	χ^2	*df*	*p*	GFI	NFI	CFI	RMSEA
Conceptual model	17.40	5	.004	.97	.93	.95	.14
Re-specified model	15.09	13	.302	.97	.94	.99	.03

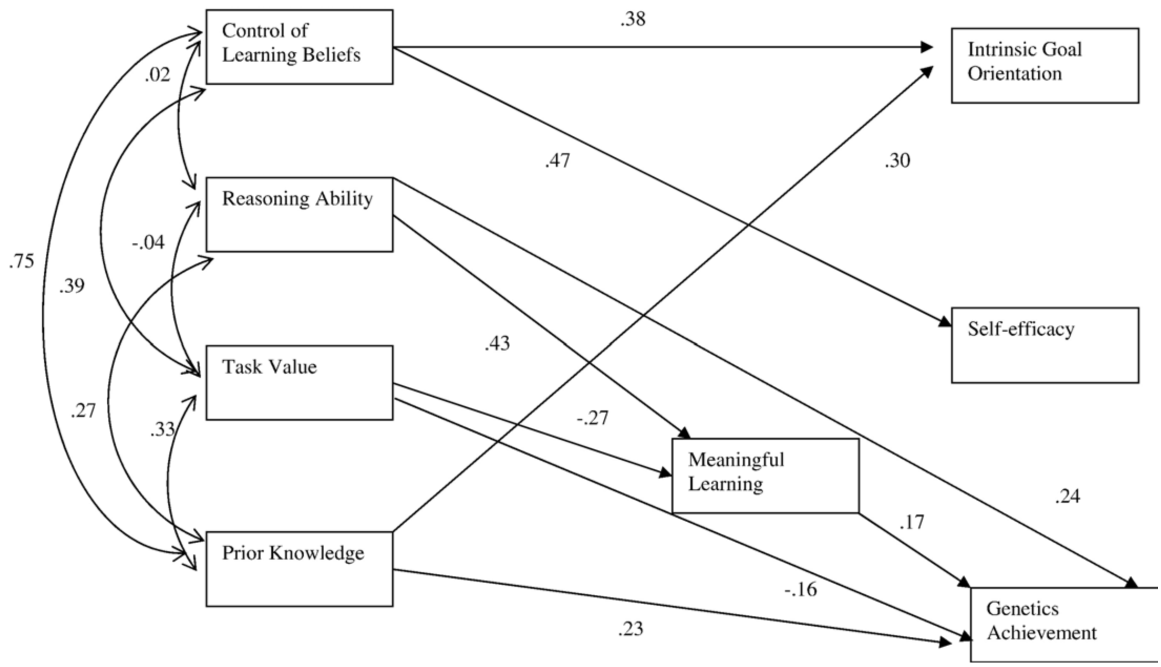

Fig. 2. Re-specified model.

In the re-specified model, learning approach, prior knowledge, task value beliefs, and reasoning ability account for 23% of the variance in achievement scores. Parameter estimates reveal that a stronger orientation towards deep learning approaches (β=.17), greater prior knowledge (β=.23), and more reasoning ability (β=.24) are all positively related to the achievement of these PBL students in their genetics course unit. Reasoning ability has the strongest total effect on achievement (β=.32). The indirect effect of reasoning ability is only .08, however, and can be attributed to this variable's strong direct (and total) effect on the learning approach (β=.43).

Task value beliefs, on the other hand, are found to be negatively related to achievement (β=−.16). Task value has a small indirect effect on achievement (β=−.04), which can be attributed to the stronger direct effect of task value on the favored learning approach (β=−.27). Taken together, reasoning ability and task value account for 27% of the variance in learning approach. This result can be summed up as follows: students with more reasoning ability appear to take a deeper approach to learning. On the other hand, students who perceive their coursework as important and useful tend to be rote learners and end up with lower achievement scores.

Further examination of the re-specified model reveals that prior knowledge and control of learning beliefs explain 38% of the variance in intrinsic goal orientation. The standardized coefficients show that both higher levels of prior knowledge (β=.30) and stronger control of learning beliefs (β=.38) are associated with higher levels of intrinsic goal orientation. In addition, control of learning beliefs is found to be positively related to self-efficacy for learning and performance (β=.47).

Results also show that the covariance between control of learning beliefs and prior knowledge is large, with a coefficient of 0.75. Therefore, those students with higher levels of prior knowledge appear to have a stronger belief that they had control over their learning.

Table 3
Direct, indirect, and total effects on motivational and cognitive variables

Variables	Intrinsic goal orientation			Self-efficacy			Meaningful learning			Achievement		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
Task value beliefs							−.27		−.27	−.16	−.04	−.20
Control of learning beliefs	.38		.38	.47		.47						
Reasoning ability							.43		.43	.24	.08	.32
Meaningful learning										.17		.17
Prior knowledge	.30		.30							.23		.23

4. Discussion

The goal of this study was to investigate the relationships among motivational variables, reasoning ability, prior knowledge, learning approach, and achievement in a problem-based learning genetics class. A generic model compiled from previously published relationships was found to provide an inadequate fit to the sample data, so a re-specified model was calculated for this study. Results show that reasoning ability has both a direct and an indirect effect on student achievement in genetics. Furthermore, re-specified model reveals that the effect of reasoning ability on achievement is mediated by learning approach. Those students with a deeper approach to learning appear to perform better on the achievement test. These findings are consistent with previous publications (Cavallo, 1996; Johnson & Lawson, 1998; Lawson & Thompson, 1988).

In addition to the benefits of reasoning ability and learning approach, the present study also reveals that prior knowledge has a direct effect on achievement. Moreover, the results show that prior knowledge is positively related to intrinsic goal orientation. Those students with higher levels of prior knowledge before the course were more likely to study for the very reason of learning and mastering the material. Another important motivational variable was task value, which was found to be negatively related to both learning approach and achievement. Contrary to findings in the literature, in this study it appears that as task values increase students are less likely to adopt a deep learning approach and obtain a high achievement score.

In the present study task value beliefs were measured using one of the MSLQ subscales, which attempts to measure three components: importance value, utility value, and intrinsic interest. Importance value refers to the importance of doing well on a task. Utility value concerns the students' perception that the material will help them achieve future goals, including career goals. Intrinsic interest is related to the students' subjective interest in the task (Pintrich & Schunk, 2002). Among these motivational beliefs, utility value is assumed to be similar to extrinsic motivation — which is generally found to be negatively associated with positive learning outcomes (Wigfield & Eccles, 2000). For this reason, it may be better to separate the constructs of importance value, utility value, and intrinsic value in conceptual models rather than consolidating them into an overall task value. By making such a distinction, it may be possible to more accurately identify the direction of the relationship between learning approach and motivation.

To sum up, the present study reveals that the main determinants of achievement in a PBL genetics course were reasoning ability, a deep learning approach, task value, and prior knowledge. Most of the relationships described in this paper are well known, and have been discussed in many previous publications. This research, however, employed a path model to reveal the pattern of relations between different motivational and cognitive variables. Path models have the ability to elucidate all the relations among several variables simultaneously, demonstrating the relative contribution of each variable to the variance in a result. In addition, this technique can investigate both indirect and direct effects, and provides statistical indices for evaluating the global fit (DeMarie, Miller, Ferron, & Cunningham, 2004).

In addition, the data in this study were collected only from PBL classes. Results show that in this learning environment, cognitive variables explain more of the variation in achievement scores than motivational variables. This point needs to be given greater attention: although the relations found among motivational beliefs agree with previous findings, in this context they did not predict achievement well. Although there were no control groups in this study, it can be proposed that the use of PBL might have led these students to develop adaptive motivational beliefs. Indeed, self-determination theory predicts that classroom structures supporting autonomy and competence promote the development of adaptive motivational beliefs and intrinsic motivation (Deci, Vallerand, Pelletier, & Ryan, 1991). Some aspects of PBL likely to enhance motivation are the presence of ill-structured, authentic problems (which provide students with an optimal level of challenge) and opportunities to develop autonomy and responsibility (Ames, 1992). Therefore, it is possible that students who did not initially have positive motivational beliefs might have developed intrinsic motivation by the time the achievement test was administered. Thus, motivational beliefs measured prior to the administration of the achievement test might be a less effective predictor of achievement in PBL classes.

Many researchers have suggested that students can develop adaptive motivational beliefs in environments which fit their needs and capabilities (Anderman & Midgley, 1997; Eccles et al., 1993; Pintrich & Schunk, 2002). In line with this idea, it has been proposed that middle school students are more likely to be intrinsically motivated in classroom environments which allow for greater control, choice, and self-regulation. Although motivational variables can be important predictors of achievement in traditional middle school classrooms, where teachers control the students and provide them with fewer decision-making opportunities, in PBL classrooms motivational variables may lose their predictive power.

Therefore, it is suggested that this study should be replicated using a control group to determine whether student motivations, learning strategies, and reasoning ability change in a PBL environment. Furthermore, it is suggested that qualitative research methods is integrated into the research design to better understand the relationship between student characteristics and the classroom context.

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