Hacettepe Üniversitesi Eğitim Fakültesi Dergisi 15 : 36 - 42 [1999]

A CAUSAL MODEL OF STUDENTS' ACHIEVEMENT IN AN INTRODUCTORY MECHANICS COURSE

Ali ERYILMAZ* Ali TATLI**

ABSTRACT: The purpose of this study is to find out the factors affecting students' achievement in introductory mechanics by employing the Factorial Modeling (FaM) procedure by using Statistical Packages for Social Sciences (SPSS) program. The subjects were 30 preservice physics teachers at Middle East Technical University (METU). Data were collected from Mechanics Diagnostic test, Science Logic test, and the information in the students' files at the METU registration office. This study had seven variates; (i) students' preconceptions, (ii) students' cognitive levels, (iii) students' science score in University Entrance Examination (UEE), (iv) students' Lycee Certificate scores, (v) students' Cumulative General Point Average (CGPA) in the University, (vi) students' mathematics achievement, and (vii) students' mechanics achievement. Bivariate correlations were computed for all pairs of variates, and a causal model of students' achievement in an introductory mechanics course was devised. The FaM procedure resulted in three variables named (i) Newtonian physics covering first three variates, (ii) Science Experience covering the fourth and fifth variates, and (iii) Mathematics aptitude covering the sixth variate. These three variables explained 62 percent of variances in the students' mechanics achievement scores (the criterion variate).

KEY WORDS: *Physics Achievement, Factorial Modeling, and Causal Model.*

ÖZET: Bu çalışmanın amacı, öğrencilerin mekaniğe giriş dersindeki başarılarına etki eden faktörleri Faktöriyel Modelleme (FaM) prosedürünü takip edip SPSS programını kullanarak bulmaktır. Çalışmaya 30 hizmet öncesi fizik öğretmeni katılmıştır. Veriler, Mekanik teşhis testi, Bilim Mantık testi ve Orta Doğu Teknik Üniversitesi kayıt dosyalarındaki bilgilerden toplanmıştır. Çalışmada yedi değişen (variates) vardır; (i) öğrencilerin önkavramları, (ii) öğrencilerin zihinsel seviyeleri, (iii) öğrencilerin üniversite giriş sınavındaki fen puanları, (iv) öğrencilerin lise diploma notları, (v) öğrencilerin üniversitedeki genel not ortalamaları, (vi) öğrencilerin matematik başarıları, ve (vii) öğrencilerin mekanik başarıları. Bütün değişenlerin bire bir ilişkileri hesaplanmıştır ve öğrencilerin mekaniğe giriş dersindeki başarılarının sebebsel modeli oluşturulmuştur. Faktöriyel modelleme üç ana değişken çıkartmıştır. Bunlar; (i) ilk üç değişeni içeren Newton fiziği, (ii) dördüncü ve beşinci degişeni içeren fen tecrübesi, ve (iii) altıncı değişeni içeren matematik kabiliyetidir. Bu üç ana değişken öğrencilerin mekanik başarı (açıklanmaya çalışılan değişen) notlarındaki değişikliğin yüzde 62'sini açıklamıştır.

ANAHTAR SÖZCÜKLER: *Fizik Başarısı, Faktöriyel Modelleme ve Sebebsel Model.*

1. INTRODUCTION

During the past ten years, physics education community has turned its attention to the problems of teaching introductory physics. The teaching of mechanics was of particular concern because mechanics, often the first subject treated in introductory physics courses, is especially troublesome for many students. Therefore, many studies have been initiated to identify the factors affecting students' achievement in introductory mechanics. Educators cited various reasons for students' difficulties with physics, especially with mechanics. Among the many factors that may contribute to students' success in learning physics, the ones most often explored are (i) mathematical skill, (ii) general levels of cognitive development, and (iii) content preconceptions.

Previous research has revealed a high correlation between students' mathematics achievement and physics achievement scores [1]. For quite a few years, many teachers in the physics community have assumed that proficiency in mathematics provides the necessary and, perhaps, sufficient condition for success in learning physics. Howe-

* Dr. Ali Eryılmaz, Middle East Technical University, Faculty of Education, Department of Science Education.
** Prof. Dr. Ali Tatlı, Middle East Technical University, Faculty of Arts and Science, Department of Physics.

ver, it was found later that mathematical skill is only one of the several factors necessary for success in physics, and a high score on a mathematics test is no guarantee of success in physics [2, 3,4].

Second, it was found that students' cognitive levels affect their achievement in physics [1, 5, 6]. Griffith [6] correlated tests of formal operational reasoning and mathematics knowledge with performance measures in introductory physics courses. A multiple-regression analysis indicated that the test of formal operational reasoning was a stronger predictor of course performance than the mathematics pre-test, particularly for the conceptual portion of the course totals. Moreover, Renner [5] noted that the Piagetian model of intellectual development tells us that each student must be engaged a subject in a manner appropriate to his or her present stage of development if he or she is to advance to the next stage. When applied to college physics teaching, this theory implies that the large fraction of introductory physics students who are at the concrete operational stage of development must observe physical phenomena directly while they themselves are manipulating the equipment. Only in this way can they progress to the formal operational stage that characterizes professionals in the field.

Finally, many investigators shared the belief that the student's preconceptions about motion and its causes have a large effect on performance in introductory mechanics [3,7]. That is why many researchers studied students' misconceptions in physics [8, 9] and how to dispel these misconceptions [10, 11].

Researchers have been trying to develop a model to integrate all these variables in order to improve students' achievement in physics. Thus, under the light of the evidences stated so far, the main problem of this study is to devise a causal model of students' achievement in an introductory mechanics course at university level.

2. METHOD

2.1. Procedure and Variables

The subjects were 30 preservice physics teachers at METU. Data were collected from Mechanics Diagnostic test, Science Logic test, and information in the students' files at the METU registration office. The study had seven variates; (i) students' preconceptions measured by the Mechanics Diagnostic test scores, (ii) students' cognitive levels measured by the Science Logic test scores, (iii) science score in University Entrance Examination (UEE), (iv) Lycee Certificate score, (v) Cumulative General Point Average (CGPA) in the University, (vi) mathematics achievement measured by the Math 151 "Calculus I" score, and (vii) mechanics achievement measured by the Physics 105 "Physics I (Mechanics)" score. Bivariate correlations were computed for all pairs of variates, and the Factorial Modeling (FaM) procedure by using SPSS was employed to analyze the correlations in support of the model's causal inferences.

2.2. Measuring Tools

Two measuring tools were used in the study; Mechanics Diagnostic test and Science Logic test. Mechanics Diagnostic test was developed and validated in this study, while Science Logic test was adopted from one of the previous studies [12].

(i) Mechanics Diagnostic test consists of 25 multiple-choice test items and it is in Turkish. The test was developed and validated by administering it to more than 1300 university students. Face and content validity of Mechanics Diagnostic test was established in three different ways. First of all, the items taken from the tests of other researchers had already been validated [8, 13, 14, 15]. Secondly, early versions of the test were examined by a Physics Professor as well as by a number of graduate students, and their suggestions were incorporated into the final version. Thirdly, interviews with 10 Introductory Mechanics students who had taken the test showed that the questions and the allowed alternative answers were quite understandable for the students.

In order to find a construct-related evidence for Mechanics Diagnostic test scores, factor analysis was used. Eigenvalue of the unique factor was found to be 2.13. Results of the factor analysis revealed that Diagnostic test measured only one dimension, which was the conceptual understanding of Mechanics, and this factor has strong influence (53%) on the variation in Mechanics Diagnostic test scores.

Reliability of Mechanics Diagnostic test was established by interviewing a group of students who had taken the test and by a statistical analysis of test results. During interviews, students gave exactly the same answers as the ones that they had given on written test. It seemed clear to the interviewer that the students' answers reflected stable beliefs rather than tentative or random responses. To compute the reliability coefficient, Kuder-Richardson 21 and Split-Half formulae were used. Values obtained for these reliability coefficients were 0.70 and 0.76, respectively. These relatively high values were indicative of a highly reliable test.

(ii) Science Logic Test (SLT) is a 12-item pencil and paper test of some of the logical operations identified by Piaget as components of formal thinking. SLT includes two or three items from each of five subscales: proportional reasoning, probabilistic reasoning, combinational reasoning, hypothetical reasoning, and control of variables. Each item is scored on a 0-to-2-point basis, with both a correct response and written indication of appropriate reasoning being required for full credit.

Based on data from testing of 366 subjects with the SLT, alpha coefficient equals 0.81 [12]. A second estimate of reliability has been obtained from retesting of 53 subjects at the end of sophomore year, who had taken the test originally as entering freshmen. This yielded a test-retest correlation of 0.79 [12].

3. A CAUSAL MODEL OF STUDENTS' MECHANICS ACHIEVEMENT

In devising the causal model, we hypothesized that the variance in students' achievement in mechanics could be explained by three variables, on each of which students in the sample differed prior to instruction. Since the introductory mechanics courses are based on conceptualization systematized by Newton, extent of the student's understanding and acceptance of Newtonian formulations should be an important factor in mechanics achievement. Causal model's first hypothesized variable, Newtonian physics, refers to the degree of acceptance of Newtonian mechanics, as opposed to an intuitive or Aristotle-like formulation of laws of motion, and this variable is specified by three variates. One is student's Diagnostic test score. The second variate specifying the Newtonian physics variable is the student's Science Logic Test score, and the third is student's Science score in University Entrance Examination (UEE). Relationship between the first variate and second variate is justified both by findings of various researchers that, formal thought appears to be a requisite for success in physics and by observations of physicists that the Newtonian formulation of mechanics essentially is an abstract logical system.

The model's second hypothesized variable, science experience, suggests that the student's acquaintance with expectations and modes of thinking in various science courses could be a factor in the student's performance in another science course. Science experience variable is associated with two variates that measure exposure to science instruction, namely, the student's High School Certificate score and the student's cumulative GPA at METU. Third hypothesized variable in causal model is the student's mathematics aptitude, which is associated with one variate. It is the student's score in Math 151 course.

Hypothesized causal model may be summarized with reference to correlation matrix shown in Table 1. Newtonian physics variable is associated with the first three input variates, and variates 4 and 5 are related to science experience variable. Variate 6 is associated with mathematics aptitude variable, and the last variate is Mechanics Achievement score in Phys. 105 course, key criterion that the model seeks to explain.

Table 2 shows varimax rotated factor matrix for mechanics achievement. Listed in the columns headed Factor Structure in Table 2 are the varimax rotated factor structure coefficients, which are multiple regression weights for the regression of each standardized

Table 1. Correlation Matrix for Input Variates and Mechanics Achievement Score (N = 30)

Variate Number and Name	1. Diagnostic test score	2. Science Logic score	3. Science score in UEE	4. Lycee Certificate score	5. Cumulative GPA	6. Math 151 score	7. Mechanics Achievement score
1. Diagnostic test score	1.00						
2. Science Logic score	0.26	1.00					
3. Science score in UEE	0.48*	0.11	1.00				
4. Lycee Certificate score	-0.23	-0.20	0.07	1.00			
5. Cumulative GPA	-0.00	-0.05	0.03	0.47*	1.00		
6. Math 151 score	0.11	-0.14	-0.06	-0.30	0.11	1.00	
7. Mechanics Achievement score	0.42*	0.15	0.33	0.15	0.26	0.02	1.00

* r is significant at = 0.05

Table 2. Varimax Rotated Factor Matrix for Mechanics Achievement

Variate	Factor Structure			Communality
	Netonian Physics	Science Experience	Math Aptitude	
1. Diagnostic test score	0.83	-0.19	0.15	0.75
2. Science Logic score	0.44	-0.37	-0.34	0.45
3. Science score in UEE	0.72	0.06	-0.12	0.54
4. Lycee Certificate score	-0.07	0.83	-0.37	0.84
5. Cumulative GPA	0.14	0.80	0.17	0.70
6. Math 151 score	0.03	-0.05	0.94	0.89
7. Physics 105 score (Physics Achievement)	071	0.33	0.06	0.62

variate on the three hypothesized variables of the causal model. When one of those weights is small, i.e., below 0.23 in absolute value, the relationship between variate and variable is usually not included in constructing a diagram of FaM causal model. In this kind of diagram (see Figure 1), elliptical boxes represent causes (variables) and rectangular boxes represent variates. Arrows are drawn from causes to variates, and loading on each arrow is an estimate of cause's influence on the variate. Table 2 also shows the communality for each variate, which is squared multiple correlation coefficient for the variate's regression on all three causes. Thus, the communality of each variate is the proportion of the variance for the variate which is explained by causal model.

Last line of Table 2 shows loadings of three variables on the criterion variable. Newtonian physics variable is estimated to exert the highest causal influences on Mechanics Achievement and Science Experience variable is estimated to exert small causal influences on Mechanics Achievement, while loading of the mathematics aptitude variable is so small that this factor could be ignored. Examining the relationships between variates and variables as the basis of factor structure in Table 2, we see that the model and its estimated structural coefficients indicate a strong causal influence of Newtonian physics variable on both Diagnostic test score and Science score in UEE. It is noted that the FaM diagram in Figure 1 displays explicitly the causal model's assertion that the Newtonian physics variable (which was specified as "the student's degree of acceptance of Newtonian physics," an abstract logical system) influences the variation in Diagnostic test score and Science score in UEE variates. Direction of arrows is from hypothesized cause (explanatory variable) to the variates.

Causal model and obtained structural coefficients also show that science experience variable has a strong influence on the variation in both Lycee Certificate score and Cumulative GPA, and it has a moderate influence on variation in Science Logic score. Minus sign of factor loadings means that sign itself has no intrinsic meaning and in no way should it be used to assess the magnitude of relationship between variates and variable. However, signs for a variable for a given factor have a specific meaning relative to signs for other variables. Different signs simply mean that variates are related to that variable in opposite directions. Science Logic Test score is also moderately influenced by both the Newtonian physics and science experience variables, so the variation in this score would be the result of an interplay among some portions of three domains, Newtonian physics, science experience, and mathematics aptitude.

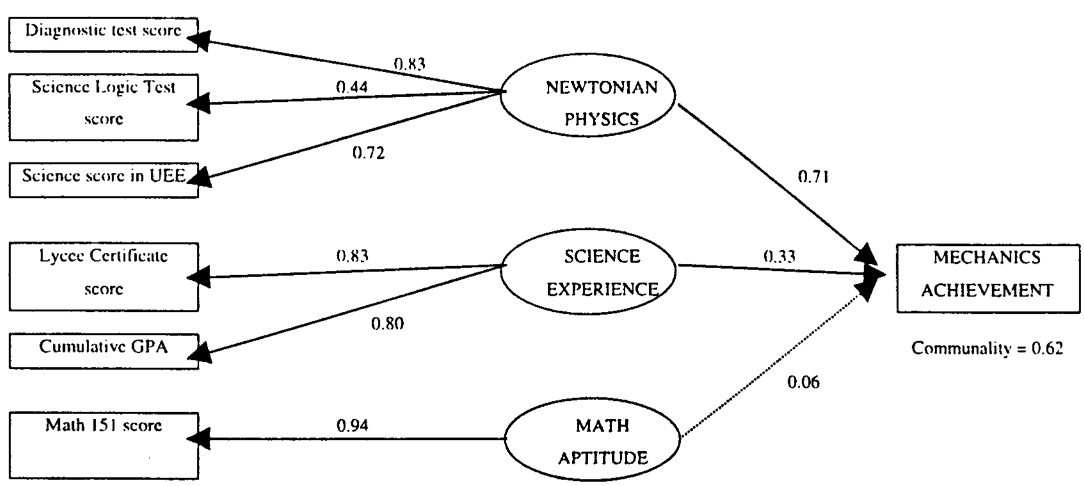

Figure 1. FaM Causal Model for Mechanics Achievement

Moreover, Lycee Certificate score is also strongly influenced by science experience variable, so variation in this score would be the result of an interplay between some portions of two domains, science experience, and mathematics aptitude. But, science experience has more influence on this score than mathematics aptitude.

Figure 1 shows a diagram of the causal model based on the FaM results given in Table 2. We should imagine that the mathematics aptitude variable could be deleted from the diagram without any material effect on the parameters of the model. A communality of 0.62 was calculated for Mechanics Achievement variate, so that the causal model explains more than half of the variance in the criterion variate. This proportion of explained criterion variance falls in the range of communalities between 0.24 and 0.51 obtained in the exemplary problem reported by Lohnes [16] and Champagne and Klopfer [4].

4. CONCLUSIONS AND IMPLICATIONS

There are several instructional implications in the proposed causal model and the FaM results. First, if improvements in university physics students' mechanics achievement are desired, efforts to enhance the students' competencies should be made in two domains: Newtonian physics and science experience. In the first domain, two kinds of instructional treatments can be expected to be of value. One obvious treatment is to offer additional discussions, problem exercises, and laboratory work that will enhance the students' understanding of Newtonian's laws of motion. If gains can be registered in both the science scores in UEE and Diagnostic test score variates, improvement in Mechanics Achievement can reasonably be expected to follow.

The second kind of suggested instructional treatment does not necessarily involve working with physics subject matter at all. FaM analysis suggests that improving student's reasoning skills will result in improved Mechanics achievement. Instruction can be provided in a non-physics content, with puzzles, verbal problems, and problems in logic constituting possible exercises for such instruction.

In domain of science experience, instructional treatment that FaM results suggest is providing students with more appropriate science courses which will be taken by students' willing, so that their success at Lycee and University will be improved.

As a result, application of FaM procedure to hypothesized causal model of mechanics achievement in university physics has confirmed the plausibility of the model. It explains the variance in the criterion variate to a satisfactory degree, and the model's principal constructed variables, Newtonian physics and science experience, together with their associated variates, offer a way of thinking about student's success in learning mechanics that is generally consistent with experiences of many university physics instructors. Newtonian physics variable apparently represents a congeries of some specific items of knowledge, understanding of certain key elements in Newtonian formulation, and particular skills in manipulating and solving formal problems. FaM results show that this variable does strongly or moderately influence the Diagnostic test score, Science Logic test score, and Science score in the UEE.

Science experience variable apparently has two straightforward components. They are the student's achievement in the course taken at Lycee and University. The FaM results show strong relationships between the science experience variable and both the Lycee certificate score and cumulative GPA at the University.

REFERENCES

1. Cohen, H. B. , Hillman, D. F. , and Agne, R. M. "Cognitive Level and College Physics Achievement". **American Journal of Physics,** 46(10): 1026-1029, (1978)

2. Hudson, H. T. and McIntire, W. R. "Correlation Between Mathematical Skills and Success in Physics". **American Journal of Physics,** 45: 470- 471, (1977).

3. Champagne, A. B. , Klopfer, L. E. , and Anderson J. H. "Factors Influencing the Learning of Classical Mechanics". **American Journal of Physics,** 48(12): 1074-1079, (1980).

4. Champagne, A.B., and Klopfer, L.E. "A Causal Model of Students' Achievement in A College Physics Course", **Journal of Research in Science Teaching,** 19: 299-309, (1982).

5. Renner, J.W. "Significant Physics Content and Intellectual Development-Cognitive Development as a Result of Interacting With Physics Content", **American Journal of Physics,** 44: 218-222, (1976).

6. Griffith, W.T. "Factors Affecting Performance in Introductory Physics Courses", **American Journal of Physics,** 53: 839-842, (1985).

7. Halloun, I. A. and Hestenes, D. "The Initial Knowledge State of College Physics Students". **American Journal of Physics,** 53(11): 1043-1048, (1985).

8. Caramazza, A., McCloskey, J., and Green, B. "Naive Believes in "Sophisticated" Subjects: Misconceptions About Trajectories of Objects", **Cognition,** 9: 117-123, (1981).

9. Van Hise, Y.A. "Student Misconceptions in Mechanics: An International Problem?", **Physics Teacher,** 26: 498-502, (1988).

10. Brouwer, W. "Problem-Posing Physics: A Conceptual Approach", **American Journal of Physics,** 52: 602-607, (1984).

11. Thornton, R.K. "Using The Microcomputer-Based Laboratory to Improve Student Conceptual Understanding in Physics", **Doğa-Turkish Journal of Physics,** 15: 316-335, (1991).

12. Griffith, W.T. and Weiner, E. "Development of a Written Test of Formal Logical Operations Used in Science". **Unpublished Manuscript** (Obtained from W.T. Griffith, Department of Physics, Pacific University, Forest Grove, OR 97116), (No Date).

13. Halloun, I.A., and Hestenes, D. "Common Sense Concepts About Motion", **American Journal of Physics,** 53: 1056-1065, (1985).

14. Maloney, D.P. "Rule-Governed Approaches to Physics-Newton's Third Law", **Physics Education,** 19: 37-42, (1984).

15. McDermott, L.C., Rosenguist, M.L., and Van Zee, E.H. "Student Difficulties in Connecting Graphs and Physics: Examples From Kinematics", **American Journal of Physics**, 55: 503-513, (1987).

16. Lohnes, P.R. "Factorial Modeling in Support of Causal Inference", **American Educational Research Journal,** 16, 323-340, (1979).