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CHAPTER 2

STUDENT CHARACTERISTICS AND LEARNING ENVIRONMENT INTERACTIONS IN MATHEMATICS AND PHYSICS EDUCATION: A RESOURCE PERSPECTIVE

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Abstract

In two studies, one on secondary mathematics education, the other on secondary physics education, data were collected on students' cognitive achievement and characteristics of students and their learning environment. In this chapter the findings of the two studies are brought together in secondary analyses. The purpose is to explore whether relations between cognitive achievement and characteristics of students and their learning environment can be interpreted from a resource perspective. Although the results only partially support the theoretical model, planning of further research from a resource perspective may be fruitful. © 1997 Elsevier Science Ltd

A resource is anything transacted in an interpersonal situation (Foa, Converse, Tönbloom, & Foa, 1993). It encompasses transactions of a variety of "commodities". Foa and his colleagues have applied the metaphor "exchange of resources", taken from economics, to other fields. However, the theory has not been adapted nor applied to education. In education, commodities include material objects, information, ability, guidance, treatment, instruction, and time. In short, a resource is then any item, concrete or symbolic, which can be possessed by people and can become the object of exchange among them. The purpose of this chapter is to reformulate Foa's resource theory and apply it to education, which is conceived of as a setting in which resource sharing takes place (Terwel, 1994a). In order to be exchanged resources first must be made available or mobilized.

From a resource theoretical perspective the process of learning mathematics or physics can be seen as a complex process of mobilization and exchange of resources. In the process of learning, the mobilization of a resource by a student can be accelerated or decelerated by resources belonging to the learning environment. Looking at characteristics of students and their learning environment from a resource perspective, three types of resources, indicated as first, second, and third order resources can be identified.

First order resources are characteristics of students with which they enter the classroom. In the present studies aptitude and gender are included as first order resources. Second order resources are student's individual perceptions of the learning environment. In the present studies student's satisfaction with mathematics or physics education is a second order resource. Third order resources are class-level characteristics of the learning environment. The mobilization of third order resources concerns the effect of class perceptions of the learning environment (mean of the students' perceptions) and the effect of treatments. In the present studies type of curriculum used and class perception of teacher quality are two third order resources included.

The mobilization of aptitude is an important factor in learning (Ausubel, 1968; Dochy, 1993). In addition, gender is related to achievement in mathematics and physics. While gender differences in mathematics and physics are small and decreasing over time, they still exist. Female students continue to score lower than males (Klein & Ortman, 1994; Freeman, 1994; Busato, Ten Dam, Van den Eeden, & Terwel, 1995). As to the mobilization of second order resources a large number of studies (Fraser, Walberg, Welch, & Hattie, 1987; Fraser, 1986) have shown that students' perceptions of the learning environment have direct and indirect effects on their learning of mathematics and physics. Effects of class perceptions of the learning environment on achievement also have been demonstrated (Fraser et al., 1987; Fraser, 1986). Finally, a large body of research on Aptitude-Treatment-Interaction has shown that interactions between aptitudes and instructional treatments exist (Chin-Hsieh LU & Hoi K. Suen, 1995; Good, Mulryan, & McCaslin, 1992; Cohen, Lotan, & Leechor, 1989; Cohen, 1994).

Based on the results from this earlier research it seems reasonable to explore a model in which the relationship between cognitive achievement and characteristics of students and their learning environment is further specified. In this model one hypothesis is that first order resources have a direct effect on the learning of mathematics and physics. Second order resources (individual student's perceptions of the learning environment) are hypothesized to have a direct effect on achievement, but also an indirect effect by affecting the mobilization of first order resources. The mobilization of first order resources can be restricted or enabled by the mobilization of second order resources. Third order resources are hypothesized to have only an indirect effect on achievement by affecting the mobilization of first and second order resources. In Figure 2.1 we give a graphic representation of this theoretical model.

Research Question and Hypotheses

The research question addressed in this study is: To what degree is this theoretical model, describing the relationship between cognitive achievement and characteristics of students and their learning environment from a resource perspective, supported by data?

Since the results of two studies are brought together in secondary analyses, it was necessary to limit the resources included in the analyses to variables that are available in both data sets. Data on these variables were originally gathered for other purposes (Terwel, Herfs, Mertens, & Perrenet, 1994; Brekelmans, 1989, also Brekelmans, Wubbels, & Créton, 1990). Included in the data sets were two first order resources (gender and aptitude), three second order resources (student perception of teacher's quality, student satisfaction in mathematics or physics education, and student perception of reality centeredness of instruction), and seven third order resources (class aptitude, class perception of the quality of the teacher, class perception of reality centeredness of instruction, class perception of satisfaction in mathematics or physics, gender composition of the class, type of curriculum, and subject).

Figure 2.1. Theoretical model.

The empirical validity of the model for both studies is tested by means of three hypotheses

- 1a There is a direct, positive effect of aptitude on achievement in mathematics and physics (first order mobilization).
- 1b There is a direct effect of gender on achievement in mathematics and physics (after controlling for the effect of aptitude). Boys achieve better than girls (first order mobilization).
- 2 There is a direct positive effect of the second order resources on achievement in mathematics and physics and/or an indirect effect by affecting the mobilization of first order resources.
- 3 The third order resources affect the mobilization of first and second order resources.

To explore the effect of the subject (mathematics and physics) on the mobilization of resources the models for mathematics and physics will be compared.

Design of the Studies

In answering the research question we bring together data from two different studies: “the mathematics study” and “the physics study”. The mathematics study involved students in an experimental curriculum (the AGO-curriculum) and students in a more traditional curriculum (non-AGO-curriculum). AGO is a Dutch acronym for Adaptive Instruction and Cooperative Learning in secondary school mathematics. The goal of the AGO project was to develop and evaluate a mathematics curriculum suitable for mixed ability groups in secondary education (Busato et al., 1995; Terwel et al., 1994). Learning in small cooperative groups is a characteristic of the experimental curriculum while students in the traditional curriculum worked independently most of the time.

The physics study involved students from classes using a traditional curriculum and classes

using an experimental curriculum (PLON). PLON is the Dutch acronym for a Physics Curriculum Development Project for general secondary education in the Netherlands. The reality centeredness of instruction has been emphasized by the developers of this curriculum and is present in the curriculum materials. For example, in this curriculum mechanics concepts are connected to experiences of students when riding their bicycles and to forces exerted on safety belts during car accidents (Van Genderen, 1985).

In both studies data were gathered on cognitive achievement and different student and class characteristics.

Mathematics Study

In the mathematics study data were gathered in 23 classes in six secondary schools. The sample included 572 students of about 14 years of age. In 15 classes the experimental curriculum was used. The other eight classes experienced the non-AGO curriculum.

To gather information on cognitive achievement a mathematics test with 22 items was administered. The test contained two subtests, mapping and equations, both containing 11 open-ended problems in accordance with both the experimental and the more traditional curriculum. The reliability of this test (Cronbach's α) was 0.87.

To determine aptitude a pretest was administered at the start of the curriculum period. It consisted of two sub-scales of the Profsystem für Schul- und Bildungsberatung (PSB) (Horn, 1969). The reliability of the test (KR-20) was 0.81. Information on gender was obtained by asking students if they were a boy or a girl.

Data on the second order resource variable student perception of teacher quality were gathered by means of a questionnaire consisting of a series of bi-polar adjectives on dimensions like clarity, friendliness and stimulation (Cronbach's $\alpha=0.94$). Satisfaction in mathematics education was measured by means of a subscale of an attitude questionnaire consisting of eight items (Cronbach's $\alpha=0.77$). Perception of the reality centeredness of instruction was measured using a scale of nine items. These items are part of the "Perception of the Curriculum In Action" questionnaire, a curriculum-oriented modification of existing measures of the perception of learning environments (Fraser, 1991). The items are answered on a five-point Likert-scale. The "Mathematics in Real-Life Situations or Contexts" scale was included in the analyses. It measures the extent to which mathematics is placed in real-life situations (Cronbach's $\alpha=0.87$).

To (roughly) characterize the third order resource variable curriculum, a dichotomous variable was used (traditional v. experimental). Gender composition of the class was represented by the proportion of girls in the class. Class aptitude and a set of class perception variables (i.e., class perception of the quality of the teacher, class perception of reality centeredness of instruction, and class perception of satisfaction in mathematics) were defined by the respective mean scores of the students' aptitudes and their perceptions of teacher quality, reality centeredness of instruction, and satisfaction.

Physics Study

In the physics study data were gathered in 64 ninth-grade physics classes taught by 64 teachers from 64 schools, totalling 1084 students of about 15 years of age. Students were from junior

general secondary education (MAVO), senior general secondary education (HAVO), and pre-university education (VWO). In 21 classes, the experimental curriculum (PLON) was used. The other 43 classes were drawn from all Dutch grade nine classes using a random sampling plan stratified for type of school (Dutch option of the Secondary International Science Study).

To gather information on cognitive achievement a standardized, internationally developed physics achievement test was administered. The 23 item test was one of the instruments used in the main part of the Second International Science Study. The reliability of the test (KR-20) was 0.61.

To determine aptitude a score was computed, based on the mean of students' report grades in the subjects mathematics, chemistry, and physics as well as the mean and standard deviation of intelligence scores of students of their type of education (MAVO, HAVO, VWO). Information on gender was obtained by asking students if they were a boy or a girl.

As a measure of the second order resource variable, student perception of teacher quality, the degree of resemblance between the perception of an individual student of the interpersonal behavior of his or her teacher and the (mean) students' perceptions of the preferred teacher was used. Data were gathered by means of the Questionnaire on Teacher Interaction (QTI). The Dutch version of the QTI consists of 77 items which are answered using a five-point Likert categorization. There is also an American version which has 64 items and a similar response scale. Several studies have shown that the QTI has a good reliability (internal consistencies between 0.71 and 0.90) and validity (Wubbels & Levy, 1993). To determine the students' perceptions of teacher quality, the resemblance between the individual student score and the preferred score was computed by means of the "similarity ratio" (Everitt, 1980).

Satisfaction in physics education was measured by means of a questionnaire on students' experience with and motivation for physics. The instrument has 30 items. Brekelmans (1989; Brekelmans et al., 1990) has demonstrated that the instrument is sufficiently reliable (internal consistencies between 0.73 and 0.89). Perception of the reality centeredness of instruction was measured by means of a scale of five items. Physics lessons can be defined as reality centered when there is a high degree of reference to previous knowledge and conceptions of students, to out of school experiences of students and to the relations of the laws and rules of physics with the everyday life of students and with natural phenomena (Wierstra & Wubbels, 1992). The internal consistency of the scale is 0.79. There also have been some positive indicators for the validity of the scale (e.g. Wierstra, 1990; Wierstra & Wubbels, 1992).

To (roughly) characterize the third order resource variable, curriculum, a dichotomous variable was used (traditional v. experimental). Gender composition of the class was represented by the proportion of girls in the class. Class aptitude and the class perception variables were defined by the respective mean scores of the students' aptitudes and perceptions of teacher quality, reality centeredness of instruction, and satisfaction in physics.

Analyses for the Mathematics and Physics Studies

The theoretical model (Figure 2.1) includes the intertwined effects of three types of resources on the achievement in mathematics and physics. The mobilization of first order resources (aptitude and gender) is specified in the model as a main effect of these variables on achievement. The mobilization of second order resources is specified as a direct effect of these variables on achievement and as an interaction effect with the first order resources. The mobilization of third order resources is hypothesized as a (cross-level) interaction of the class level variables with the first

and second order resources and the interaction between these two. In order to assess interaction effects appropriately, the assessment of the accompanying main effects is necessary.

In this study the effect of the subject (mathematics or physics) on the mobilization of second order resources, also was explored. Because data from two different studies were used and data for mathematics and physics from the same students was unavailable, the effect of the subject is explored by comparing the results of the mathematics and physics studies.

The set of hypotheses is conceptualized in a multilevel framework, since individual students are nested in classes. As a result, in testing our hypotheses, the random coefficient model of multilevel analysis was used. The random coefficient model (De Leeuw & Kreft, 1986; Longford, 1993; Hox, 1995) is also known as the variance decomposition model (Aitkin & Longford, 1986) and hierarchical linear model (Goldstein, 1995; Bryk & Raudenbusch, 1992).

The random coefficient model was forwardly used in the analysis. Four subsequent models were used during testing. *Model 0* indicates which part of the total variance of mathematics or physics achievement can be attributed to the student level and which part to the class level. *Model 1* assesses the degree to which the student variance is bound by the entrance variables (first order resource). First, the effect of aptitude is assessed. Then, the effect of gender is estimated, controlling for differences in aptitude (net effect of gender). Subsequently, *Model 2* permits an investigation of whether there is an effect of the second order resource variables by introducing students' perceptions of teacher's quality, their satisfaction in mathematics and physics education, and their perceptions of the reality centeredness of instruction, as well as interactions with aptitude and gender into the equation. Finally, *Model 3*, offers an opportunity to assess to what degree the occurrence of between-class differences in mean achievement scores (intercepts), between-class differences in effects of the first and second order resource variables and interactions between them (slopes) can be explained by means of third order resource variables.

During the testing procedure, it is determined whether the $-2 \cdot \log$ likelihood ratios as model-fit parameters of subsequent models differ from each other, taking into account the difference in degrees of freedom. All variables were entered separately and in combination into the analyses. Non-significant coefficients (the 95% confidence level is used) were fixed to null in further runs. In order to interpret comparatively the fixed coefficients across mathematics and physics, the variables were normalized on their own level. Student variables were normalized on the student level, class variables were normalized on the class level. Dichotomous variables were coded -1 and $+1$ (-1 for girls, $+1$ for boys; -1 for the traditional curriculum, $+1$ for the experimental). The ML3E-program (Prosser, Rasbash, & Goldstein, 1991) was used in the analyses.

Results

The results are presented in three sections. First, the results for the mathematics study are summarized. Next, those for the physics study are presented. Finally, the results of the two studies are compared.

Achievement in Mathematics

The outcome of *Model 0* shows that 50.4% of the total variance in achievement is present within classes and 49.6% between classes. This percentage is extremely high in comparison with

other studies into class effects. (See, among many other studies, the studies in Raudenbusch and Willems (1991), which reported about 15%). The finding in the present study reflects the differences between classes as a consequence of the categorical system and the streaming practices in the Netherlands. All school types and streams were included in this study.

For the effect of aptitude on achievement (*Model 1*) the coefficient (0.31) was significant with the expected sign. Also, the coefficient of gender was significant (0.06); boys achieve somewhat better than girls (after controlling for the effect of aptitude). Boys with the same aptitude as girls had mathematics achievement scores that were 0.13 standard deviation higher than those of girls.

In *Model 2* we added the student level learning environment variables as well as their interactions with gender and aptitude. Only a direct effect of satisfaction on mathematics achievement was significant (the regression coefficient=0.23). An increase of one standard deviation on the satisfaction scale results in an increase of 0.23 standard deviation in the achievement scores. All student variables together in *Model 2* explained 24.4% of the variance at the student level. The regression coefficient for aptitude was corrected by the introduction of satisfaction in mathematics to 0.26. However, the effect of the first order resource variable gender disappeared by introducing the second order resource variable satisfaction to the model. This means that gender can be considered as an approximation of satisfaction in mathematics education. The effect of gender in *Model 1* was brought about by satisfaction (boys enjoy mathematics more than girls). So, of the first order resource variables only aptitude plays a role in students' learning of mathematics. It could be concluded that the discussion of gender differences in mathematics could be replaced by a discussion of differences in enjoying mathematics.

Model 3 concerns the between-class differences in the intercepts and slopes of the regressions of first and second order resource variables, along with their interactions. No between-class differences in the regression slopes were found. Only class aptitude contributed to the explanation of between class differences in mean achievement scores in mathematics (positively, the regression coefficient=0.47). Adding class aptitude to *Model 2* reduces the unexplained class level variance by 55.4%.

For the final model (*Model 3*) the correlation between achievement scores and the prediction of these scores by the model is 0.87. In light of the limited number of resource variables, the quality of prediction of the achievement scores by our final model is quite good.

Achievement in Physics

The outcome of *Model 0* shows that 22.8% of the total variance of achievement is present within classes and 77.2% between classes. This percentage is lower than that of the mathematics achievement scores and more in line with other studies into class effects. As with the mathematics study, the coefficient of the effect of aptitude on achievement in *Model 1* was significant and with the expected sign (0.34). An increase of one standard deviation on the aptitude scale results in an increase of 0.34 standard deviation on the achievement scale. Also the coefficient of gender turned out to be significant (0.24); boys achieved higher than girls. Girls with the same aptitude as boys had physics achievement scores that are 0.47 standard deviation lower than that of boys. So, the two first order resource variables, aptitude and gender, play a role in students' learning of physics.

In *Model 2* the student-level learning environment variables were added as well as their interactions with gender and aptitude. As with mathematics, only the direct effect of satisfaction on

achievement was significant (the regression coefficient=0.08). An increase of one standard deviation on the satisfaction scale results in an increase of 0.08 standard deviation in the physics achievement score. Satisfaction in physics, gender, and aptitude together explained 19.2% of the student level variance. With physics, the regression coefficient of gender is only slightly corrected by satisfaction.

Model 3 concerns the differences among classes in the intercepts and slopes of the regressions of first and second order resources, and their interactions. As with mathematics, however, no between-class differences in the regression slopes were found. Analyses of differences between classes in intercept of the regression equation showed that only class aptitude contributed to the explanation of between-class differences in mean achievement. As with mathematics, this was the only relevant variable at the class level to explain between-class differences. Adding this variable to the variables in Model 2 reduces the unexplained variance at the class level by 21.5%. For the final model (Model 3), the correlation between achievement scores and scores based on the prediction by the model was 0.47. In light of the limited number of resource variables, the quality of prediction of the achievement scores by our final model is satisfactory.

Comparison of the Mathematics and Physics Results

The second and third order resource variables that are important for achievement are the same for both subjects. The size of the effect of satisfaction and class aptitude were lower for physics than for mathematics. Of the first order resource variables, aptitude plays a role in students' learning of both mathematics and physics. The size of the regression coefficients is similar. For gender the results of the analyses differ. With mathematics, differences between boys and girls can be explained when the satisfaction variable is introduced in the model. The quality of the prediction of achievement scores from the model is better for mathematics than for physics ($r=0.87$ and 0.47 respectively).

Conclusions and Discussion

In the theoretical model a direct effect of first order resource variables, gender and aptitude, on cognitive achievement was assumed. The hypotheses concerning these effects were confirmed by the data. In mathematics and physics, high aptitude students have higher scores on achievement than low aptitude students. Males outperform females in achievement in mathematics and physics.

The theoretical model also assumed a direct effect on achievement of second order resource variables (perception of teacher quality, satisfaction in mathematics or physics education, and perception of reality centeredness of instruction) and an indirect effect through aptitude and gender. The hypotheses concerning the indirect effect were not confirmed. Furthermore, only satisfaction had a direct effect on achievement (in the expected direction). Interestingly, the pattern is similar for mathematics and physics. However, the influence of satisfaction in mathematics is much higher than it is in physics. In the case of mathematics, introducing satisfaction in the model has the effect of making the effect of gender disappear. One recommendation consistent with the results of this study is to make mathematics more interesting and gender differences may vanish. A similar recommendation for physics will probably be less effective.

Finally, the theoretical model assumed an indirect effect of third order resource variables (gender composition of the class, curriculum, class aptitude, class perception of teacher quality, of reality centeredness of instruction, and class perception of satisfaction in mathematics or physics) on achievement through second order resource variables. The hypotheses about these effects were not confirmed. Striking, however, was the similarity in outcomes in mathematics and physics. In both studies of the third order resources included, only class aptitude has an (unspecified) effect on achievement. This effect is larger for mathematics than for physics. If it is true that class aptitude has a direct effect on achievement, then it becomes extremely important to discuss the practice of ability grouping from a resource theoretical perspective. If class aptitude is a powerful resource in education, then it becomes questionable to deny students, probably those who are most in need, access to this resource which implies not enable them to profit from the resources of fellow students.

Although the results of these two studies only partially support the theoretical model, further research on the intertwined effects of different students' entrance and learning environment characteristics on cognitive achievement from a resource perspective could be fruitful. The variables used in the secondary analyses are limited by the data sets of the studies that were brought together. Other variables such as learning styles, perceptions of specific teacher behavior, and structure in the classroom, are interesting candidates to be tested in the theoretical model.

Last but not least, because only perceptions of students have been investigated and no classes have been observed (see for example Fraser & Tobin, 1991), it is not known whether differences can be attributed to different frames of reference students use in their perceptions of the learning environment, or to differences in, for example, the way teachers interact with boys and girls. Therefore, caution must be used in interpreting these results.

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