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THE USE OF PROBLEM-SOLVING TECHNIQUES TO DEVELOP SEMIOTIC PROCEDURAL KNOWLEDGE MODELS ABOUT MAGNETISM AND THEIR ROLE IN LEARNING FOR PROSPECTIVE SCIENCE TEACHERS

İsmail Yılmaz[1]

Abstract

This study identifies prospective science teachers' knowledge and achievement levels in terms of the variables affecting their problem-solving techniques. The aim is to develop a semiotic procedural knowledge model that will enable them to better understand complex subjects, such as magnetism. The model was established by generalizing the nodes from a semiotic model developed for multiple questions. Assessment and control mechanisms for learning systems were used in the model to maximize the production quality and efficiency of the prospective science teachers' functional behaviors. The data for this study were collected through four measurement tools. The data were analyzed using VDOIHI scoring, and the knowledge and achievement levels were identified. The development of the semiotic procedural knowledge model was based on these knowledge and achievement levels. Results suggest that semiotic models are needed for improving the knowledge processes of prospective science teachers.

Keywords: Procedural knowledge; knowledge level; achievement level, semiotic model, semiotic procedural knowledge level

Introduction

By studying magnetism, prospective science teachers learn not only about crucial properties about nature but also important aspects of scientific knowledge, including the epistemology of scientific knowledge as well as its information value, semiotic expressions, simplicity, and logic. When prospective teachers learn about magnetism, they also learn about the constructed nature of scientific knowledge. Magnetism reveals a basic understanding of a unique characteristic of science, namely that two independent scientific theories can combine into a single theory over time. Any attempt to teach science and scientific knowledge should take this fact into consideration. In science education, the prerequisite for understanding magnetism is to improve prospective teachers' procedural knowledge. This, in turn, will lead to a corresponding improvement in their experiences and individual regulating mechanisms (Epstein, 1986; Hudspeth & Pribram, 1990; Lawson et al., 2000; Thatcher, Walker & Guidice, 1987).

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[1] Sakarya University, Department of Science Education, Turkey, iyilmaz@sakarya.edu.tr

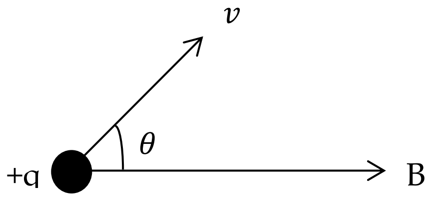
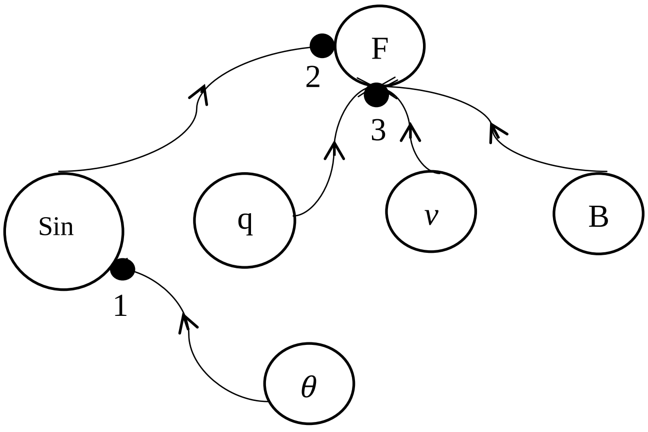


Figure 1. Semiotic Model For Magnetism

Much of what we know is comprised of procedural and declarative knowledge (Dacin & Mitchell, 1986; Runco & Chand, 1995). Procedural knowledge, which involves information about a rational behavior, describes how a procedure can be carried out in accordance with specified rules (Özenli, B2, 1999). It is possible to present procedural knowledge on a semiotic model. We consider a simple example to demonstrate how procedural knowledge can be presented on a semiotic model for magnetism. Imagine that a particle with a charge +q enters a magnetic field with velocity v (see the figure 1 below). If we want to calculate the force on the charge, and if we are provided with q, v, B, and θ, we can calculate force $\mathbf{F}_B$ as $F_B = |q|vBsin\theta$. The calculation is carried out as follows: calculate sine of θ angle; record the result; then, multiply q and v by B and record the result. Finally, multiply the former result by the second result, and record this result. This series of calculations is a procedural knowledge model. Diagram 1 presents how this procedural knowledge model can be displayed as a semiotic model. The diagram is a *semantic network* that illustrates the *procedural knowledge model* for the charge particle entering the magnetic field. In the semantic network, circles represent the basic components of the force whereas the black spots surrounding the circles symbolize synapses (stimulants that trigger contact between the node they belong to and the other nodes). Synapses only exist in two states: excited or non-excited. If a synapse gets excited, the node it belongs to also gets excited and the excitement is transmitted along the arrows (i.e., relationship connections) stemming from the node until they arrive at the synapses where they end. A synapse is excited only if all the arrows coming to it are active (excited). This type of a network is a *semantic network.* In order for the network to be excited, some of the nodes have to be excited externally, which happens when the node is provided with some external data. This excitement will spread to the other nodes in the network. The process will be stabilized, with the network becoming statically excited. The reference numbers for the synapses (1, 2, and 3) also represent the numbers for the procedures. Problem-solving should start with data, which are represented by q, v, B, and θ. The data and their connections are presented in Diagram 1. Starting with Synapse 1 implies starting the procedure for calculating the sine. In order to excite Synapse 1, the node of θ must be excited. For the example provided here, the node of θ is excited externally, that is, by inputting data θ. In this manner, the externally excited node of θ excites Synapse 1, starting Procedure 1 for sine calculation. Procedure 1 is the calculation of the sine of θ. When Synapse 1 is excited, it initiates Procedure 1 and excites the node of "Sin." The excitement of the node of "Sin" implies that sine has been calculated. The excitement of the node of "Sin" excites Synapse 2. When Synapses 2 and 3 are excited, Procedure 2 is initiated, and the node of F is excited. Procedure 2 is the multiplication of Synapses 2 and 3. Synapse 3 is excited when q, *v,* and B are input. In other words, Synapse 3 is excited when nodes q, *v,* and B are excited externally. The excitement of Synapses 2 and 3 leads to the start of the procedure for force calculation using the formula $F_B =$

$|q|vBsin\theta$ (Procedure 2). The excitement of the node of F, in turn, means that necessary procedural information has been used to complete the calculation. The model is called a *semiotic model.* The transition of the network to a static state suggests that procedural information has been used and "procedural knowledge" has been defined. This defined procedural knowledge is a type of procedural knowledge generated through problem-solving techniques. The semiotic model generated here is a *semiotic procedural knowledge model,* and it can be used to explain other procedural knowledge subjects associated with magnetism. The stimulants (data) and excited (nodes) components of a *semiotic procedural knowledge model* generated for solving a problem should be defined and adapted to more than one situation. Stimulants can be defined as *given-asked.* The definition is also a variable and can be called the given-asked variable. Variables are defined for the nodes as well as for the procedures for the nodes. These variables are a) "free-body diagram (FBD)" for graphics and figures used for problem-solving techniques, b) "formula" for formulas used for problem-solving techniques, c) "operation" for the last node where the operations are carried out, d) another variable of "formula" that allows for problem-solving techniques in which all the formula knowledge associated with problem-solving techniques is defined, e) "basic math" for mathematics knowledge, and f) "scientific knowledge" for scientific knowledge used for problem-solving techniques. These variables in problem-solving techniques can be classified as two mechanisms for a *learning system*. In this way, the stimulants and excited components of the *semiotic procedural knowledge model* can be defined through *assessment* and *control* mechanisms.

Diagram 1. A Semantic Network That Models the Calculation of the Magnetic Force



In this study, certain procedures will be called operations whereas certain formulas will be called rules. The rules and their procedural operations will be considered to form the prospective teachers' procedural knowledge. When the result (e.g., the number obtained from the multiplication of the two numbers recorded following two calculations in the sample given above) is the desired value, it will be called "achievement." The knowledge and achievement levels can be analyzed through probability and possibility calculation statistics for data variables (VDOIHI) (Yılmaz, 2011). The adaptation of the scoring system of the VDOIHI statistic to the example given above is as follows:

Step 1: For $\frac{F_B}{1} = \frac{|q|}{1}\frac{v}{1}\frac{B}{1}\frac{sin\theta}{1}$, each "smallest meaningful unit" is assigned a probability score of 1 (The scores imply the following: 0 = absent, 1 = correct, and -1 = incorrect. In VDOIHI, or in particular, in its combined stage statistic, when one of the data is negative, the stage involving the steps is called a negative stage.)

Step 2: $\frac{sin\theta}{1} = \frac{score_1}{1}$

Step 3: $\frac{|q|}{1}\frac{v}{1}\frac{B}{1} = \frac{score_2}{1}$

Step 4: $\frac{score_1}{1}.\frac{score_2}{1} = \frac{result}{1}$ ("result" respresnts the the value of the force to be found)

The desired score (BGS): "The sum of probability scores for Step 1" + "The sum of probability scores for Step 2" + "The sum of probability scores for Step 3" + "The sum of probability scores for Step 4 = BGS.

For our example, the desired score (BGS) = 5 + 4 + 2 + 3 = 14

The scoring provided above is also used for the measurement data. If data include a "smallest meaningful unit," which is desired and assigned a probability score of 1, the smallest meaningful units in all the stages are scored. Next, these scores are added together to come up with P, namely the current score. The knowledge level is found when the current score is divided by APS, namely the desired score. As for the achievement level, the correct result for the data (the value of the force in the example given above) is assigned 1 point independently of the calculation of the knowledge level. Next, it is divided by the desired result score (the value of the force in the example is assigned a score of 1, which is the desired result score) to come up with the "achievement level." Appendix 1 presents an example scoring, calculation, and interpretation procedure.

Before the *semiotic procedural knowledge model* is formed, it is necessary to focus on the role of the "model" in instruction. In education, the role of the teacher is not only to convey formal information but also to explain the objective of learning and form positive and constructive behavioral models among the students. Teachers must enable students to acquire the skills needed for solving problems. In doing so, teachers create and shape the fundamental principles of scientific and technological research and thinking (Özenli, 1999, p. C2). Additionally, the roles of "control," "the control mechanism," "the assessment mechanism," "objective," and "objective-oriented systems" will be defined following Özenli (1999).

The semiotic procedural knowledge model can be generated for more than one problem with variables, assessment, and control mechanisms. In addition to creating a positive and constructive behavioral model in students' minds, this model may also help them create and form necessary scientific skills, research abilities, and thinking skills. One such semiotic model developed for magnetism is presented in Diagram 2.

Prospective science teachers can improve their knowledge by making accurate decisions, adopting appropriate selection processes, dividing data into its sub-components in order to select an accurate option, and assembling these sub-components in an objective-oriented way. This process should start with procedural knowledge. Prospective teachers' ability to establish connections among more than one dataset, make decisions, and choose the best option is associated with declarative knowledge. Prospective science teachers' procedural knowledge and declarative knowledge enable them to construct and develop scientific knowledge inductively. Thus, it is possible to standardize the learning/teaching process of prospective teachers. To do so, learners must be adaptive and objective-oriented. Controlling instructional processes does not mean suppressing individuals' willpowers; instead, it means understanding natural rules and using them optimally.

In science education, prospective teachers must have high procedural knowledge levels so they can construct scientific knowledge and have high levels of declarative knowledge. In addition, this knowledge can help them understand complex subjects like magnetism. Previous studies suggest that improvements in procedural knowledge contribute to the development of teaching methods and help enhance the overall educational process (Andre & Ding, 1991; Drummond et al., 1998; Howe et al., 2000; Johnson & Star, 2007; Kamouri et al., 1986; Kirkhart, 2001; Willingham, Nissen & Bullemer, 1989).

The present study identifies prospective science teachers' knowledge and achievement levels according to the variables affecting their problem-solving techniques, and develops a corresponding semiotic procedural knowledge model. This model will enable them to better understand subjects, such as magnetism, that have more than one epistemological level. The procedural knowledge is studied through problem-solving techniques. Determining how the variables for prospective teachers' knowledge and achievement levels affect their problem-solving techniques reveals their procedural knowledge structures. By measuring the variables, it is also possible to show the degree of the assessment and control mechanisms. This study presents a standardized semiotic procedural knowledge model for magnetism in science education.

Methodology

In this study, the prospective teachers' knowledge structures were represented by their knowledge and achievement levels, which were the dependent variables of the study. The prospective teachers' scientific knowledge structures were defined according to the variables affecting problem-solving techniques (independent variables) in procedural knowledge. The data collection instruments were designed according to the independent variables, and the prospective science teachers were asked to solve each question by separating each variable from one another. The independent variable data were used to calculate the dependent variables using VDOIHI. The process of improving the prospective science teachers' procedural knowledge structures was studied using a statistical method and a semiotic model.

The Measurement and Statistical Method

The dependent and independent variables were defined in relation to the prospective science teachers' procedural knowledge about solving magnetism-related problems. The dependent variables were the knowledge and achievement levels. These two variables constituted the knowledge structure of the prospective teachers. Their knowledge levels were defined through the independent variables. Their achievement levels, on the other hand, were defined independently of the independent variables and accounted for by the effects of the variables. Improvement in their knowledge structures was defined in accordance with the independent variables. The data were collected through a qualitative case study, during one week after the prospective teachers had finished studying magnetism. In their curriculum, magnetism was covered in the second term within the scope of the course *General Physics II*. The participants were first-year science teaching students. The data were collected through four measurement instruments with a total of 35 prospective teachers.

Measurement Tool 1 (MT1), which contained six open-ended questions, was administered to the prospective teachers in order to measure their knowledge about how to carry out a procedure concerning magnetism in accordance with specified rules. MT1 was intended to measure the prospective teachers' procedural knowledge structures, namely their knowledge and achievement levels in magnetism. Two types of independent variables, namely knowledge-level variables (KLVs) and procedural variables (PVs), were identified. For the independent variable KLV, the knowledge levels needed to solve each question on the MT1 define the dependent variable. The different levels were given-asked, free-body diagram, formula, and operation. Since the KLV was measured at each stage, these stages were called the independent KLV. The knowledge level (dependent variable) for each of these independent variables was identified through the IS, APS, ANS, NAPS, and SS scores. The VDOIHI, or specifically its combined stage statistic (Yılmaz, 2011; Yılmaz & Yalçın, 2011), was used to score the independent KLVs in solving the questions and to calculate the IS, APS, ANS, NAPS, and SS scores. The same statistic was used for the other scoring and calculations in the study. The calculation of the IS, APS, ANS, NAPS, and SS scores for each independent KLV occurred in three stages: positive, negative, and neutral. If an independent KLV happened to have more than one stage, these stages were considered to have formed a combined stage. The scores in the positive stages were used to calculate the APS, those in the negative stages the ANS and NAPS, and those in the neutral stages the IS. The percentage values of these IS, APS, ANS, NAPS, and SS scores, calculated for each independent KLV, indicate the effect of that independent KLV on the achievement level. Appendix 1 presents an example of a similar calculation. In this way, the KLVs were associated with the achievement levels. The other dependent variable identified was the achievement level. The achievement level was represented by the ASS score. What the prospective teachers wrote for each question was assigned a Cb score and associated with the desired result score (CB) in order to calculate the ASS, or their achievement level.

The independent variables that affected both the procedural knowledge and achievement levels of the prospective teachers were formula knowledge concerning magnetism, basic math knowledge, and scientific knowledge. These variables were called procedural variables (PV). Thus, the participants' procedural knowledge structures were studied through seven variables: four KLVs and three PVs.

The variable of formula knowledge represented the formula procedures to be used for solving the questions about procedural knowledge on the MT1. In accordance with the definition of procedural knowledge, the variable required that the procedures for a given subject should be known before any procedural knowledge could be formed. Measurement Tool 2 (MT2) was administered to the prospective teachers in order to measure this procedural knowledge. MT2 contained 36 questions about formulas for magnetism, which were used for solving the questions on the MT1. The measurement tool was designed to identify the effect of formula procedures on the prospective teachers' knowledge and achievement levels. Each correct answer was assigned one point, and the final score was divided by the desired score (36) to come up with the percentage value. The percentage value was used to identify the effect of formula knowledge.

The variable of formula knowledge represented the formula procedures for MT1, and each question on MT2 was linked with one or more questions from MT1. Thus, it was possible to test whether the prospective teachers had knowledge about the procedures used for solving the questions on the MT1 and identify variables related to their procedural knowledge structures. The total score obtained from the MT2 was used to identify the effect of the variable of formula knowledge on the prospective teachers' procedural knowledge structures.

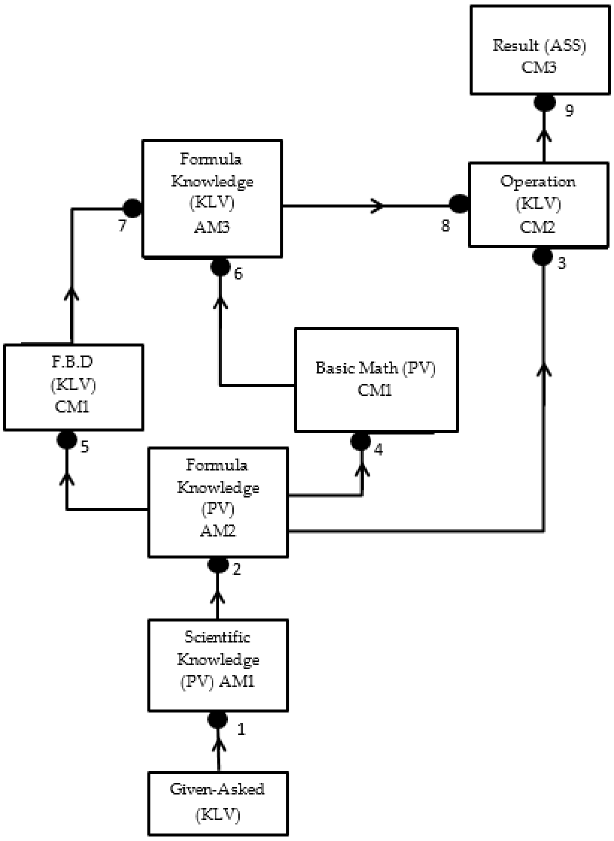
Basic math knowledge was another independent procedural variable. Measurement Tool 3 (MT3) was designed to identify the effect of basic math knowledge on the prospective teachers' procedural knowledge structures. MT3 contained 50 questions involving basic mathematical operations associated with MT1. The prospective teachers were presented with basic mathematical expressions and asked to write down equivalents. Each correct equivalent was assigned one point. The total score was divided by the desired score to determine the percentage value. The percentage value was used to identify the effect of basic math knowledge. Each question on MT3 was associated with one or more MT1 questions. Thus, it was possible to test whether the prospective teachers had knowledge about basic mathematical operations that could be used to solve the questions on MT1, and identify the effects of this independent variable on their procedural knowledge structures.

The last independent variable was scientific knowledge. Measurement Tool 4 (MT4) included 14 questions about magnetism. Half of the questions were about declarative knowledge whereas the other half were about mathematical logical knowledge. Each correct answer was assigned one point. The total score was divided by the desired score (14) to determine the percentage value and the effect of this independent variable on the prospective science teachers' procedural knowledge structures. All the calculations in the present study were made through the package software program developed for the VDOIHI.

Semiotic Methodology

By replacing the nodes with the variables, one can establish a semiotic model for the prospective teachers' solving of the procedural knowledge questions concerning magnetism. For example, a stimulant piece of data (given-asked (KLV)) is input to the system for a general condition concerning magnetism. The data activates (excites) a synapse of scientific knowledge (PV) with which it is linked. The excited scientific knowledge excites a synapse of formula knowledge (PV). If the excited formula knowledge is comprised of one formula, it excites a synapse of operation (KLV). The excited operation, in turn, excites a synapse of result (ASS) and gets stabilized. Unless more than one formula in the formula knowledge (PV) can excite the synapse of operation, it excites either a synapse of basic math or a synapse of free-body diagram (FBD). In the event that basic math knowledge is excited, the synapse of formula knowledge (KLV) is excited if an appropriate formula is developed. The excited synapse of formula knowledge (KLV) excites the synapse of operation. The excited synapse of operation, in turn, excites the synapse of result and becomes stabilized. More than one formula in the excited formula knowledge (PV) might excite the synapse of FBD (KLV) without exciting basic math knowledge. In that case, the synapse of FBD excites the synapse of formula knowledge (KLV). The excited synapse of formula knowledge (KLV), in turn, excites the synapse of operation. The excited synapse of operation excites the synapse of result and becomes stabilized. This semiotic model is presented in Diagram 2.

Diagram 2. Procedural Knowledge Models That Illustrate the Semantic Network in Magnetism



KLV: Knowledge-Level Variable PV: Procedural Variable
AM1, AM2 ve AM3: Assessment Mechanism CM1, CM2 ve CM3: Control Mechanism

Diagram 2 is a semantic network that illustrates the direction of the model for solving the questions about procedural knowledge. This "model for solving procedural knowledge questions" can be used as a semiotic model for learning. The findings of the present study will be useful for establishing the semiotic models of prospective science teachers for subjects such as magnetism that are related to procedural knowledge. This semiotic model is based on the mathematical connections (especially logical functions) among the percentage values of APS for the variable in each node. These percentage values are also called the accuracy values of the variables.

The maximization of the quality and efficiency of the prospective science teachers' functional behaviors and productivity will be explained through the assessment and control mechanisms, as shown in Diagram 2. The nodes in Diagram 2 will represent either the assessment or control mechanisms, depending on the roles they assume. The nodes of scientific knowledge (PV), formula knowledge (PV), and formula knowledge (KLV) will represent the assessment mechanisms for maximization. In accordance with the roles they assumed, the nodes of FBD, (KLV), basic math (PV), operation (KLV), and result (ASS) will be defined as the control mechanisms for maximization.

Furthermore, this diagram is valid not only for educators but also those being educated. In order for the teachers to benefit from the improvements in their procedural knowledge processes, the path must be followed from the data (given-asked) to the result (ASS). For the present study, the path will go through the variables. The assessment mechanisms will be defined via objective-oriented systems. The scientific knowledge that particular data are associated with is assessed and determined by the objective-oriented systems in the variable of scientific knowledge (PV) (the excitement of the node of scientific knowledge (PV) through the excitement of Synapse 1). Next, the formulas for that scientific knowledge will be assessed and determined by the objective-oriented systems in the variable of formula knowledge (PL). If the objective-oriented systems determine one formula for solving the question, the next step is to proceed to the variable of operation (KLV) and determine the result through the control mechanisms. If more than one formula has been determined in the variable of formula knowledge (PV), the formula that will lead to the result is determined by proceeding to the variable of formula knowledge (KLV) through the use of the control mechanisms for either the variable of basic math (PV) or FBD (KLV). The formula that will lead to the result is assessed and determined by the objective-oriented systems in the variable of formula knowledge (KLV). The next step proceeds to the variable of operation (KLV) and uses the control mechanisms in order to determine the result. Which objective-oriented systems or control mechanisms are used in the assessment mechanisms is determined by the percentage values of APS for the variables. One can define the assessment and control mechanisms in learning systems by interpreting the percentage value of APS as the measurement of self-organization in the assessment mechanism and accuracy value/level in the control mechanism.

Statistical Results

Table 1 presents the calculations of the scoring of the data obtained from the four measurement tools. The IS, APS, ANS, NAPS, and SS scores for the KLVs are presented separately. The last column represents the participants' overall knowledge levels according to their mean scores in the four KLVS. The variable accounting for the achievement levels of the prospective science teachers is represented by the ASS score. The ASS scores are provided in the last row of the column that includes the calculations for given-asked (KLV). The same column also provides the PV values. MT2 represents the value for the variable of formula knowledge, MT3 for the variable of basic math knowledge (PV), and MT4 for the variable of scientific knowledge (PV).

Table 1. Findings on the Scoring Based on the Data Obtained From the Four Measurement Tools

Point/ Variable	Given-Asked	Free-Body Diagram	Formula	Operation	Sum of Variables
IS(S)	0.00	0.01	0.02	0.06	0.02
APS(S)	0.03	0.28	0.17	0.24	0.18
ANS(S)	-0.01	-0.02	-0.01	-0.15	-0.05
NAPS(S)	0.00	0.02	0.01	0.05	0.02
SS(S)	0.96	0.67	0.79	0.50	0.73
MT2	0.36				
MT3	0.71				
MT4	0.30				
ASS	0.43				

The prospective science teachers had an ASS score of 0.43, which suggests the extent to which they used their procedural knowledge about magnetism, followed specified rules, and achieved the result (new knowledge) (Table 1). In addition, their mean scores in the KLVs indicated that their general positive knowledge level (APS) was 0.18, their negative knowledge level (ANS) was 0.05, their positive knowledge level in negative knowledge (NAPS) was 0.02, and their neutral knowledge level (IS) was 0.02. The participants' knowledge about the specified rules for a procedure (or knowledge/question) in magnetism was represented by the APS value, which was far lower than their achievement level (2.39). This finding suggests that the participants were able to apply certain procedures and rules without this being reflected in their knowledge level. This might be the reason why their achievement level was 0.43, a rather low value. Their scores for the procedural variables, namely formula knowledge, basic math knowledge, and scientific knowledge, were 0.36, 0.71, and 0.30, respectively. Out of these three values, only basic math knowledge had a value higher than the achievement level. One reason why the achievement level was higher than the knowledge level might be the fact that the participants had a relatively higher value for the variable of basic math knowledge (0.71).

Table 1 presents the IS, APS, ANS, NAPS, and SS knowledge-level calculations for the independent KLVs, namely given-asked, free-body diagram, formula, and operation. The findings of the IS, APS, ANS, NAPS, and SS knowledge levels for each independent KLV, as well as their association with the achievement level, are interpreted below according to the percentage values of probabilities.

All the calculations for given-asked (KLV) are presented in the second column of Table 1. Significantly, this variable represented where the planning for solving the question took place. Its importance to procedural knowledge was that it was the independent KLV that involved the identification of the procedures as well as their order. The effects of the variable on the achievement level were as follows. The participants' score/knowledge in the positive stage (APS) positively affected the achievement level (ASS) by 3%. Their knowledge in the neutral stage (IS) did not influence the achievement level (0%). Their negative knowledge (ANS) negatively affected the achievement level by 1%. Their positive knowledge in the negative stages (NAPS) did not affect the achievement level (0%). The zero score (SS), which indicated the level of unknown knowledge for the variable, negatively affected the achievement level by 96%. The extent to which this independent KLV positively affected the achievement level is equal to the aggregate of the APS and NAPS scores at most. In other words, the variable could be argued to have positively influenced the achievement level by 3% at most. On the other hand, the extent to which the variable negatively affected the achievement level is equal to the aggregate of the IS, ANS, and SS scores at most. In other words, the variable could be argued to have negatively influenced the achievement level by 97% at most.

The second variable for the achievement level was free-body diagram, one of the independent KLVs. The calculations for this variable are presented in the third column of Table 1. This variable helped determine accurate formulas for the solution by establishing a connection between what was asked and given. Furthermore, its importance to the procedural knowledge is its role as an independent KLV where some of the procedural rules could be identified. The effects of the variable on the achievement level were as follows. The participants' knowledge in the positive stage positively affected the achievement level by 28%. Their knowledge in the neutral stage negatively influenced the achievement level by 1%. Their negative knowledge negatively affected the achievement level by 2%. Their positive knowledge in the negative stages had the potential to affect positively the achievement level by 2%. The zero score, which indicated the level of unknown knowledge for the variable, negatively affected the achievement level by 67%. The variable could be argued to have positively influenced the achievement level by 30% at most, whereas it could be argued to have negatively affected the achievement level by 70% at most.

The third variable for the achievement level was formula, another independent KLV. The calculations for this variable are presented in the fourth column of Table 1. This was the variable where the basic procedures for solving a question were determined. The effects of the variable on the achievement level were as follows. The participants' knowledge in the positive stage positively affected the achievement level by 17%. Their knowledge in the neutral stage negatively influenced the achievement level by 2%. Their negative knowledge negatively affected the achievement level by 1%. Their positive knowledge in the negative stages had the potential to affect positively the achievement level by 1%. The zero score, which indicated the level of unknown knowledge for the variable, negatively affected the achievement level by 79%. The variable could be argued to have positively influenced the achievement level by 18% at most, whereas it could be argued to have negatively affected the achievement level by 82% at most.

Three of the KLVs, namely given-asked, free-body diagram, and formula, represented where the procedures and rules were determined for procedural knowledge. On the other hand, operation was the last variable where the rules of the procedures identified in the previous three variables were used to achieve a result or produce knowledge. The calculations for this variable are presented in the fifth column of Table 1. The effects of the variable on the achievement level were as follows. The participants' knowledge in the positive stage positively affected the achievement level by 24%. Their knowledge in the neutral stage negatively influenced the achievement level by 6%. Their negative knowledge negatively affected the achievement level by 15%. Their positive knowledge in the negative stages had the potential to affect positively the achievement level by 5%. The zero score, which indicated the level of unknown knowledge for the variable, negatively affected the achievement level by 50%. The variable could be argued to have positively influenced the achievement level by 29% at most, whereas it could be argued to have negatively affected the achievement level by 71% at most.

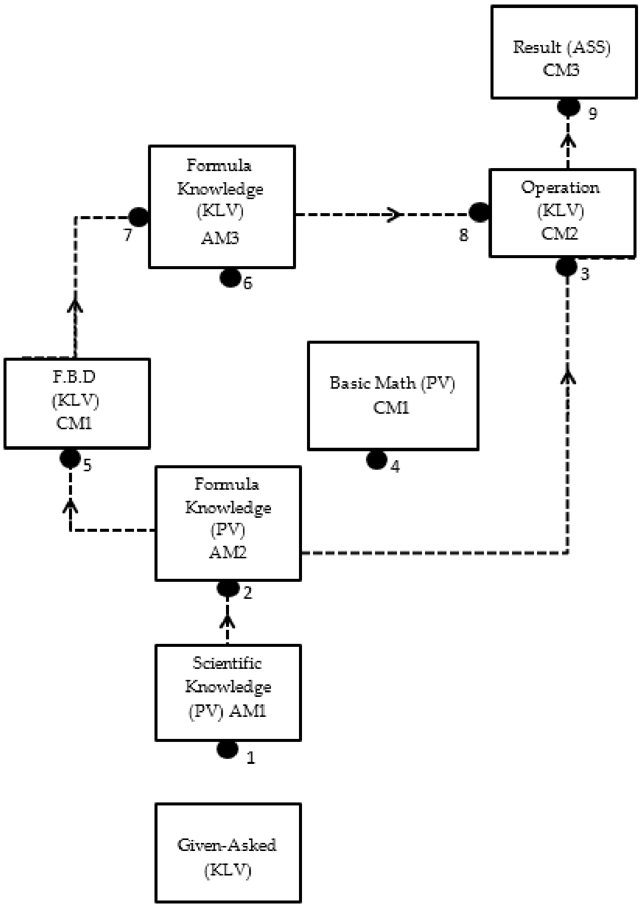
The PVs, which collectively influenced the prospective science teachers' knowledge and achievement levels (APS and ASS), and identified their procedural knowledge structures, were tested through the MT2, MT3, and MT4. The related calculations are presented in the second column of Table 1. Results show that the variable of formula knowledge (MT2) positively affected the procedural knowledge structures by 36%. In addition, the variable of basic math knowledge (MT3) positively affected the procedural knowledge structures by 71%. Finally, the variable of scientific knowledge (MT4) positively affected the procedural knowledge structures by 30%. These findings suggest that the value closest to the achievement level (0.43) was formula knowledge (0.36). On the other hand, the value closest to the knowledge levels (0.03, 0.28, 0.17, and 0.24) was scientific knowledge (0.30).

Semiotic Results

A comparison among the APS values of the independent knowledge-level variables (KLV), the values of procedural variables (PV), and the ASS values indicated that the values for all variables, except for basic math (PV), were lower than the ASS value. This suggests that two potential paths in Diagram 2 were used by the prospective teachers as they proceeded from the excitement paths to the variable of operation (KLV). The fact that the variable of given-asked (KLV) was excited by 3% suggests that this variable was not used by the prospective science teachers. Thus, the semiotic model is based on the acknowledgement that the stimulant data excited the variable of scientific knowledge (PV) by 30%. When the node of scientific knowledge (PV) was excited, the scientific knowledge that the data were associated with could be identified with an accuracy level of 30%. The node, in turn, excited Synapse 2, which meant starting the procedures to identify the formulas that would lead to the result. The formulas were identified with an accuracy level of 36%, and the node of formula knowledge (PV) was excited. The excitement of the node excited Synapses 3, 4, and 5. The percentage values for the nodes that these synapses were linked to were 24, 71, and 28, respectively, which suggests that Synapse 4 was not excited. The reason for this is that after a node excited with an accuracy level of 36% excited the node of basic math with an accuracy level of 71%, it should have excited Synapse 6 with an accuracy value higher than 17%. In that case, the node of formula knowledge (PV) excited either Synapse 3 or Synapse 5. Since the percentage value for the excitement of the node of FBD (KLV) was closer to the percentage value for formula knowledge (PV), it must have been Synapse 5 that was excited.

In other words, more than one formula that would lead to the result must have been identified in the excited node of formula knowledge (PV). Thus, Synapse 5 was excited, starting the procedures related to drawing figures to identify the relevant formula. These procedures were used with an accuracy level of 28%, and the node of FBD (KLV) was excited. The node, in turn, excited Synapse 7, starting the procedure to select the formula already identified in the node of FBD (KLV). The formula was identified with an accuracy level of 17%, and the node of formula knowledge (KLV) was excited. The procedures for obtaining the relevant result were completed with an accuracy level of 24%, exciting the node of operation (KLV). This node, in turn, excited Synapse 9 and started the procedure to identify the accurate result. The result was identified with an accuracy level of 43%, and the node of result (ASS) was excited, leading to stabilization. Through that excitement, the relevant formula might have been identified in the node of formula knowledge (PV), thus exciting Synapse 3. In this case, the node of operation (KLV) was excited and stabilization was achieved. Diagram 3 presents the semantic network for the semiotic procedural knowledge models.

Diagram 3: Procedural Knowledge Models That Illustrate the Semantic Network in Magnetism



Since the variable of given-asked was where the stimulant data needed to be divided into its components, this variable had no influence on the assessment and control mechanisms. Thus, the data were accepted into the first assessment of the variable of scientific knowledge (PV) without being divided into its sub-components. The options for the stimulant data input in the MT1, which were designed to measure data following the definition of procedural knowledge, enabled the prospective teachers to be self-organized by 30% (0.30) for this variable, and this maximized a utility function. Since the participants were able to self-organize by only 3% for the variable of given-asked, it was more likely to make an inert decision in the variable of scientific knowledge (PV) as a wrongly-tolerated system. The data for this variable were assessed, and a corresponding decision was made. Next, the variable of formula knowledge (PV) was considered in order to assess the formulas for this knowledge (the second assessment). For this variable, the assessment mechanisms were used, and a corresponding decision was made. The participants were self-organized for this variable by 36%. Afterwards, they decided on one formula and proceeded to the variable of option (KLV), where the control mechanisms would be employed, or they identified more than one option and proceeded to the variable of basic math (PV) or FBD (KLV). If a certain utility function was maximized in the variable of formula knowledge (PV) with a risky decision and one formula was identified, the participants might have used the control mechanisms (the second control) in the variable of operation (KLV) and proceeded to the result. The data and formulas were used in the variable of operation, the operation options were reduced with an accuracy level of 24%, and entropy reduction, one of the control mechanisms, was used. The fact that the values for the variable of formula (PV) and the other variable of formula (KLV) were 0.36 and 0.17, respectively, suggested that maintenance of variances and selective oblivion were not used in the control mechanisms. Following the reduction in the variable of operation, the next step was to proceed to the result (ASS) where the third and last control took place. In this control variable, the result should have been identified through a reduction with an accuracy level of 43%; however, the percentage value of the result was higher than the assessment and control paths. This meant that the prospective teachers used this control variable as a wrongly tolerated objective-oriented system. If a certain utility function was maximized in the variable of formula knowledge (PV) with a cautious decision and more than one formula was identified, the variable of basic math (PV) was not used as a control mechanism because of the reason specified in the procedural knowledge model. In that case, FBD (KLV) was used as the control mechanism. This variable was the first control mechanism. The procedures for drawing figures and entropy reduction (28%) were used in order to determine the formula that would lead to the result with a cautious decision of 36%. The next step was to proceed to the variable of formula (KLV) where the assessment mechanisms were used to determine the formula that would lead to the result. The result might have been reached as follows: the participants were self-organized in the variable of formula (KLV) by 17%, made an inert decision to select one formula out of several options, proceeded to the variable of operation (KLV) where the control mechanisms were used, and used control methods on the decision coming from the variable of formula (PV).

Statistical Conclusions

The participants' positive knowledge level was 0.03 (APS: 3%) and their negative knowledge level was 0.01 (ANS: 1%) in given-asked, an independent KLV that was needed to solve the questions in the MT1. Such low scores suggest that they had not been involved in planning how to identify and carry out the specified rules for the procedure. In addition, their scores for the other KLVs, namely 0.28, 0.17, and 0.24 (APS: 28%, APS: 17%, and APS: 24%), as well as their knowledge level (0.43, or ASS: 43%) and formula knowledge (PV)(0.36, or MT2: 36%), were higher than the knowledge level for the variable of given-asked. This suggests that the prospective teachers knew about the procedures and rules for magnetism at a higher level than their knowledge level for this variable, but they failed to get involved in planning. If they had been involved in planning, the optimal value they would have received would have been approximately the value for the variable of formula knowledge (PV) (MT2: 0.36). Similarly, previous studies by the author of the present study on similar topics concluded that the KLV with the lowest value was given-asked (Yılmaz, 2011; Yılmaz and Yalçın, 2012a; Yılmaz and Yalçın, 2012b). These studies found that the participants' positive knowledge level for the variable of given-asked was 0.12 (APS: 12%), that their achievement level was 0.66 (ASS: 66%), and that their value for the variable of formula knowledge (P.V.) was 0.54 (MT2: 54%).

Given the findings of the present study, as well as the previous ones, it could be argued that prospective teachers' proper planning for the variable of given-asked while attempting to solve procedural knowledge questions would make their positive knowledge levels approach the value for the variable of formula knowledge (PV). Even in that case, however, it would be necessary to increase the value for the variable of formula knowledge (PV) before any correlation could be established between the variable of given-asked and the achievement level. In order to improve the prospective science teachers' procedural knowledge and make it easier for them to solve related questions, it is necessary to increase the value for the variable of formula knowledge (PV) and their positive knowledge level for the variable of given-asked. In other words, the value for the variable of formula knowledge (PV) should be increased, which should be accompanied by some planning on how to identify and carry out the rules for a particular procedure.

The participants' positive knowledge level for free-body diagram (FBD) was 0.28 (APS: 28%). Moreover, their overall positive knowledge level was 0.30 (APS + NAPS: 0.28 + 0.02 = 30%) whereas their overall knowledge level was 0.33 (APS + NAPS + IS + ANS: 0.28 + 0.02 + 0.01 + 0.02 = 33%). These values suggest that the prospective teachers partially knew the rules of a particular piece of procedural knowledge concerning magnetism. Likewise, previous studies on prospective teachers' procedural knowledge structures (Yılmaz, 2011; Yılmaz and Yalçın, 2012a; Yılmaz and Yalçın, 2012b) concluded that the positive knowledge level for this variable was 0.12, the overall positive knowledge level was 0.17, the overall knowledge level was 0.35, and the value for the variable of formula knowledge (PV) was 0.54. These values are similar to the present findings. Other studies on declarative knowledge (Yılmaz, 2011; Yılmaz & Yalçın, 2012a; Yılmaz & Yalçın, 2012c) reported that the overall knowledge level for this variable was 0.00 and the value for the variable of formula knowledge was 0.59. Given these findings, it could be argued that the value for the variable of formula knowledge (PV) (MT2:0.36), which tested whether the rules of procedural knowledge were known, should be increased first before any attempt to increase the knowledge level for the variable of free-body diagram. It should be ensured that the rules of procedural knowledge could be selected in terms of the rules of the relevant procedure. In the present study, the extent to which this association could be established for selection was represented by the formula knowledge levels (KLV). Afterwards, it would be more appropriate to enhance the permanency of the formula knowledge levels (KLV) and increase the FBD knowledge levels, which could make it easier to identify rules.

The KLV where the prospective science teachers would identify the rules of a relevant procedure to obtain procedural knowledge was formula knowledge. For this variable, the participants' positive knowledge level was 0.17 (APS: 17%), their overall positive knowledge level was 0.18 (APS + NAPS: 0.17 + 0.001 = 18%), and their overall knowledge level was 0.21 (APS + NAPS + IS + ANS: 0.17 + 0.01 + 0.02 + 0.01 = 21%), all of which constituted rather low values for the variable. These findings suggest that the prospective teachers had an unsatisfactory level of knowledge about the rules of procedural knowledge. In addition, the knowledge level for formula knowledge (KLV) was lower than the value for the variable of formula knowledge (PV) (MT2: 0.36), which implied that they were unable to associate known rules with the relevant procedure. On the other hand, similar studies (Yılmaz, 2011; Yılmaz & Yalçın, 2012a; Yılmaz & Yalçın, 2012b) reported that the positive knowledge level for this variable was 0.55, the overall positive knowledge level was 0.57, the overall knowledge level was 0.60, and the value for the variable of formula knowledge (PV) was 0.54. This discrepancy might have resulted because the topic of magnetism made it more difficult for the prospective teachers to associate known rules with the relevant procedure when compared to Newton's laws of motion, which was the topic of the previous studies. The implication of these findings for science education is that Newton's laws of motion should be covered earlier than magnetism laws. Furthermore, procedural knowledge levels about preceding subjects should be enhanced before rules concerning magnetism can be taught and learned.

In the present study, it was the variable of operation where the prospective teachers were supposed to carry out operations to achieve the desired result in accordance with the rules of a particular procedure. Not only the knowledge level but also the achievement level could be determined for this variable. The participants' positive knowledge level for this KLV was 0.24 (APS: 24%), their overall positive knowledge level was 0.29 (APS + NAPS: 0.24 + 0.05: 29%), and their overall knowledge level was 0.50 (APS + NAPS + IS + ANS: 0.24 + 0.05 + 0.06 + 0.15 = 50%). These variables had the highest values, excluding the positive knowledge level for FBD. This finding suggests that the prospective teachers attached importance to identifying the result, though without planning and applying the rules for a particular procedure. It is possible the prospective teachers focused on the result because they were influenced by "testing culture." This also implies that knowledge is not constructed but memorized, which has negative implications for the teaching profession. What should matter most is the comprehension of knowledge, and the first step towards this is procedural knowledge.

One of the reasons why the prospective teachers' knowledge level in the negative stages (ANS: 0.15) for the variable of operation was higher than the other independent KLVs was that they had difficulty in associating their basic math knowledge (PV) (MT3: 0.71) with the application of the rules. Alternatively, their overall positive knowledge level (0.29) was very close to the value for the variable of scientific knowledge (PV) (0.30, or MT4: 30%), which suggested that they relied on incorrect knowledge about the rules.

Semiotic Conclusions

An assessment of the semiotic procedural knowledge models indicated that the directional flow between the variable of formula knowledge (PV) and the variable of operation (KLV) was such that would make the node of formula knowledge (PV) excite Synapse 3. The control for the variable of FBD (KLV) did not ensure maintenance of variance for the options determined for the variable of formula knowledge (PV) with a cautious decision and accuracy level of 36%. In addition, an inert decision was made with an accuracy level of 17% for the variable of formula knowledge (KLV). Therefore, the node of formula knowledge (PV) excited Synapse 3 without exciting Synapse 5. In the semiotic procedural knowledge models for the prospective teachers, the node of scientific knowledge (PV) was excited without the stimulant data being divided into its sub-components for the variable of given-asked. With the excitement of this node, the relevant scientific knowledge was identified with an inert decision as a wrongly tolerated system, and Synapse 2 was excited. The excitement of this synapse caused the node of formula knowledge (PV) to be excited. In this node, one single formula was maximized with a risky decision, and Synapse 3 was excited. The synapse, in turn, excited the node of operation (KLV). In this node, Synapse 9 was excited following the use of data and formulas as well as reduction in the operation options. Synapse 9, in turn, excited the node of result, and the result was determined with the use of a wrongly tolerated objective-oriented system as the assessment mechanism.

If semiotic procedural knowledge models are designed with consideration to the assessment and control mechanisms, increased quality can be achieved in the processes by which educators shape the minds of their students. The findings of the present study suggest that semiotic models are needed to improve knowledge processes because the prospective teachers made decisions that would not lead to the expected result in the assessment mechanisms. In addition, they failed to establish a proper balance between maintenance of variations and selective oblivion. Below are semiotic procedural knowledge models that illustrate how prospective teachers could have obtained the expected result through objective-oriented systems and by establishing a balance between the control mechanisms.

First, the stimulant data should be divided into sub-components for the variable of given-asked, and then a decision should be made for the variable of scientific knowledge for the knowledge to which the data belong. Next, the formulas that will lead to the result in the variable of formula knowledge (PV) should be determined, to ensure a proper balance between maintenance of variations and selective oblivion either for the variable of basic math or FBD. Moreover, this will determine the accurate formula for the variable of operation (KLV) that will lead to the result and a proper balance between risk and caution. For the variable of operation, the data and formula should be used, and an accurate entropy reduction should be made. Finally, the result should be determined through a proper balance between maintenance of variations and selective oblivion.

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Appendix 1.

Sample Question: A proton moves with a velocity of $3x10^9$ m/s in a direction at an angle of 90^0 to a magnetic field of 0.5 T in the direction of +x. Find the size of the magnetic force affecting the proton.

The Desired Way

Given-Asked:

$\frac{+}{1}\frac{q}{1} = \frac{1,602x10^{-19}\quad C}{1}$

$\frac{B}{1} = \frac{0,5\quad T}{1}$

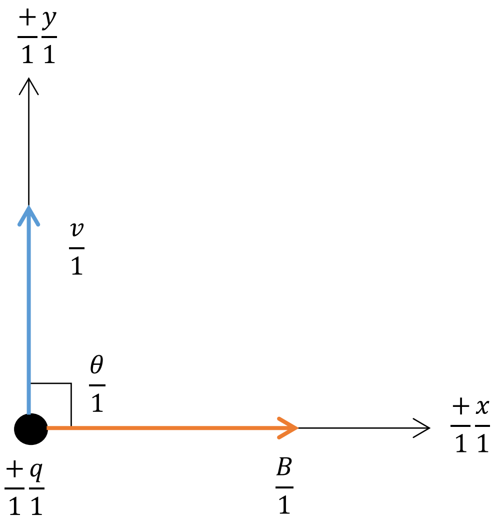
$\frac{\theta}{1} = \frac{90^0}{1}$

$\frac{v}{1} = \frac{3x10^9\quad m/s}{1}$

$\frac{F_B}{1} = \frac{N\,?}{1}$

The desired result (BGS) = 3 + 2 + 2 + 2 + 2 = 11

Free-Body Diagram:



BGS= 9

Formula:

$\frac{F_B}{1} = \frac{|q|}{1}\frac{v}{1}\frac{B}{1}\frac{\sin\theta}{1}$

BGS= 5

The Current Way

Given-Asked:

$\frac{q}{1} = \frac{1,602x10^{-19}\quad C}{1}$

$\frac{B}{1} = \frac{0,5\quad T}{1}$

$\frac{?}{?} = \frac{?}{?}$

$\frac{v}{1} = \frac{3x10^9\quad m/s}{1}$

$\frac{F_B}{1} = \frac{N\,?}{1}$

The current score (P): 2 + 2 + 2 + 2 = 8

Free-Body Diagram:

P=0

Formula:

$\frac{F_B}{1} = \frac{|q|}{1}\frac{v}{1}\frac{B}{1}$

P= 4

Operation:

$$\frac{F_B}{1} = \frac{|q|}{1}\frac{v}{1}\frac{B}{1}\frac{sin\theta}{1}$$

$$\frac{F_B}{1} = \frac{1{,}602x10^{-19}}{1}\frac{3x10^{9}}{1}\frac{0{,}5}{1}\frac{sin90}{1}$$

$$\frac{F_B}{1} = \frac{2{,}403x10^{-10} \quad N}{1}$$

BGS = 12

The desired result score (CB) = 1

$$\frac{F_B}{1} = \frac{|q|}{1}\frac{v}{1}\frac{B}{1}$$

$$\frac{F_B}{1} = \frac{1{,}602x10^{-19}}{1}\frac{3x10^{9}}{1}\frac{0{,}5}{1}$$

$$\frac{F_B}{1} = \frac{2{,}403x10^{-10} \quad N}{1}$$

P = 10

The current result score (Cb) = 1

Operation:

Calculation and Interpretation:

Given-Asked:

$$APS = \frac{P}{BGS} = \frac{8}{11} = 0{,}72$$

The knowledge level for given-asked is 0.72. This knowledge level has the potential to affect the achievement level in a positive way by 72%.

Free-Body Diagram:

$$APS = \frac{P}{BGS} = \frac{0}{9} = 0$$

The knowledge level for free-body diagram is 0. This knowledge level does not have the potential to affect the achievement level.

Formula:

$$APS = \frac{P}{BGS} = \frac{4}{5} = 0{,}8$$

The knowledge level for formula is 0.8. This knowledge level has the potential to affect positively the achievement level by 80%.

Operation:

$$APS = \frac{P}{BGS} = \frac{10}{12} = 0{,}83$$

The knowledge level in operation is 0.83. This knowledge level has the potential to affect the achievement level by 80%.

The achievement level (ASS): $ASS = \frac{Cb}{CB} = \frac{1}{1} = 1$

The achievement level is 1 (100%).