

Modeling and Predicting Scientific Thinking Skills of University Students Using a Data Mining Tool

Orhun Alp ORAL¹, Ö. Özgür TANRIÖVER², Mohamad SOUBRA³

¹ Microsoft Canada Excellence Center Vancouver, BC, Canada

^{2,3} Computer Engineering Department, Ankara University, Ankara, Turkey

alp.oral@microsoft.com, tanriover@ankara.edu.tr, m.soubra@ankara.edu.tr

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Abstract— In order to model and predict scientific thinking skills of university students, scientific thinking test with psychological test and demographical information survey had been administered to students. Results obtained from the test and survey was analyzed to make pattern analysis. During preprocessing, outliers and invalid data were eliminated. Clustering methods, PCA analysis, regression and decision tree models were used during analyzing stage. As data analytic tools KNIME toolkit and Weka knowledge flow is used for further analysis and model generation. Socio-economic factors are found to have direct influences on the level of critical thinking.

Keywords— *Scientific thinking, data mining approach, multiple tests.*

1. INTRODUCTION

Scientific thinking (a.k.a. critical thinking) involves applying skepticism to ideas and forming testable hypotheses. This type of thinking can lead to experiments, and it can help people develop skills for determining whether something they hear or see is true. It is simply defined as “knowledge seeking”. Since childhood, humans start to make up theories about life that will be of aid to organize the way they think about life.

There is general agreement that critical thinking is a desirable attribute in university settings, and that its development ought to be facilitated in students. It is observed that assignments that develop critical thinking skills have taken a central stage in many of classrooms [1]. There are clear indications that development of students’ abilities to think critically about engineering problems and design projects is an important educational objective[2].

Educators and researchers generally agree that critical thinking as a skill can be developed in students [5]. However, there is increasing evidence that not all students improve their critical thinking skills during their studies in higher education (e.g. [6], and [7]).

Although use of information technologies seems promising [4] generally accepted guidelines for the effective promotion of critical thinking skills development are still lacking. One important reason for the absence of such guidelines is that

there are many different factors believed to influence students’ critical thinking skills development and application[3]. Without adequate understanding of how these various factors influence critical thinking, it is difficult to confidently design programs for promoting critical thinking skills development that would address individual or shared needs of target groups of students.

Psychological testing is a field characterized by the use of an individual’s “samples of behavior” to assess the individual’s psychological construct. The “sample of behavior” is a term related to beforehand prescribed tasks allocated to the individual. These tasks are basically done through an objective and standardized pencil-paper test as a result, these test would reveal the individual’s mental and/or behavioral characteristics such as cognitive ability, aptitude, emotional functioning and personality. The psychological testing is referred as to the administration of psychological tests thus, it is also considered to measure unobserved constructs called “latent variables”.

The aim of this study is to analyze and understand which factors influence scientific thinking skills for university students. A survey results about demographical information and three tests namely: Attitude test, scientific thinking skill test, academic support test had been administered to 408 undergraduate students in Akdeniz University (Turkey) had been conducted.

In order to model and predict scientific thinking skills of University students, scientific thinking test with psychological test and demographical information survey results done to students are used. In the analysis stage, clustering methods, PCA analysis, and regression decision tree model were utilized whereas KNIME toolkit and Weka knowledge flow were used to make further analysis and model generation. It should be highlighted also that to ensure the reliability, outliers and fraud data were omitted. The information obtained from analysis was evaluated by an academic domain expert from Social Science Institute. The results of application of data analytics are presented.

2. RELATED WORK

There has been some significant work regarding issues of scientific or critical thinking skill factors.

Related to the level critical thinking, the authors of [8] differ between students who receive education in early age and those who do not. As a result, the authors related the issue of critical thinking with the low, medium, and high Socioeconomic Status (SES) of the student. The authors proposed a model based on the Delphi approach to define the characteristics of critical thinking. The test was based on concepts of transferability and metacognition. It was considered that through sequences of questions and images, it is possible to assess the student's level of ability for each of the skills included in the model. 3rd and 4th graders for different schools were subjected to the model. The authors cited two main limitations of the model such as that was used is the cultural context, and that the study sample was unbalanced towards the high SES students. The results assured that SES has an influence on critical thinking in which that it was particularly evident when observing that the standard deviation among students in the high SES school decreases over time, increasing homogeneity among students, while the standard deviation remains the same in the other schools.

In another study [9] it has been claimed that applied studies could result in unreliable results since curriculums have a huge influence for students influencing critical thinking aspects. This was demonstrated in the first approach done by the authors; taking the study on a group of 1st year in engineering where the first attempt was unproductive for two reasons. The first was that the author used a pre and post test methodology using the Cornell Critical Thinking Test [16] that was not well-suited as a measure of the multifaceted nature of critical thinking in engineering. The second reason is related to the overloaded curriculums as mentioned above. In the second attempt the authors decided to use time series methodology inspired by internal assessment techniques related to multiple choice questions. The answers were contrasted with the more standardized Critical Thinking VALUE rubric [15]. This allowed to

identify any similarities and differences between their evaluations and the VALUE rubric.

The authors of [10] states that critical thinking is a hard thing to assess or test and links critical thinking with practice. The example given was based upon midwifery and nursing undergraduates. The author proposed a test which depended on the content validity through a two staged process which involved preliminary expert view and mapping the draft items to the concepts of critical thinking. The mapping was done against the consensus definition of critical thinking in nursing. Another aspect is Expert review: judgement-quantification which involved an evaluation of survey items by a panel of experts. The Assessment of Critical Thinking in Midwifery (CACTiM) (Preceptor/Mentor version) was the second stage. As a result, a high item mean indicated that overall preceptors assessed midwifery students were displaying a reasonably high level of critical thinking in practice thus the success of the test. The author warns that the study could have been influenced by recall bias.

The authors of [11] argues that critical thinking is developed through practice and exercise through listening to classical music, taking walks, recording all ideas down in a notebook, holding debates, etc. A sample of chemical and biochemical engineering graduate students was selected. The students left the first session to a number of research topic and return with fresh ideas based on the answers they found. Then students individually wrote three to five answers to a question on a note card, and then share one idea with the larger group. This process is repeated twice and records of the brainstorming results from the last year's class are used as a challenge to the current class. It was realized that the test result agreed with the above discussed criteria.

The author of [12] relates critical thinking with non-traditional classroom settings, sociocultural factors, and learning environment. A survey was proposed that will basically question which are related to the following a survey was conducted at the end of the semester involving 39 Korean university students. It consisted of ten questions addressing the impact of the higher-level questioning activities on critical thinking and student engagement. In addition, a Focus Group Discussion (FGD) composed of members from each class was held to further assess the approaches used in the study. As a result, Korean students were found uncomfortable with communicative activities involving questioning and critical thinking and thus teachers in Korea should promote such activities, challenging students to overcome the perceived associated discomfort.

The authors of [13] proposes the teaching of critical thinking is important for all students in all subjects. Different disciplines are characterized by particular approaches to critical thinking. The authors proposed a

study upon pre-service teachers participated during their science methods courses from three different programs: elementary, middle and secondary education. 120 individuals was selected as teachers' representatives. The study was done by utilizing a Critical Thinking Attribute Survey (CTAS)[17]. The CTAS encompassed ten major attributes related to socio centricity and the ability to solve certain problems. The critical thinking attributes as presented in the CTAS included four science standards: 1) Inquiry, 2) History and the Nature of Science, Science in Personal and 3) Social Perspectives and 4) Science and Technology which makes them to be perceived as having more attributes of critical thinking. As a result, more than 50% of total responses was marked as high for the science standards.

The author of [14] remarks that critical thinking is taught in British schools as a skills-based rather than content based subject. The author gives an example that international students always receive much lower ratings, not only because they write in a foreign language, but also because they cannot think critically, presumably because they have not been trained to do so before they came to the UK clarifying, where English-speaking academics criticize international students' critical thinking and academic writing skills. This seems to contain an implicit claim that international students are inferior to their British counterparts, since critical thinking and academic writing skills are the main indicators of an academic's intellectual worth. It is important to acknowledge that new skills cannot be learnt instantly, or quickly thus, the author advises international students that are willing to receive education in UK to develop some skills through reading academic literature. In this case a person's critical thinking level is measured through the person's ability to reason adequately in a working environment.

From the reviewed literature, it can be seen that differences arise with sample spaces such as college vs university students and samples from different cultures. Some studies were concerned with particular aspects in a certain domain (i.e. nursing, etc.) and others only concerned to enlighten the reader about the critical thinking instead of giving a proper hypothesis or design to find the predominant factors. In this study we use a data mining centric methodology to analyze the critical thinking factors especially in the domain of university studies. We tended to take basic aspects of critical thinking and link them to socio-economic traits seen in the Turkish society. We also tried to find unexpected results by utilization of data mining specifically; segmentation and clustering, in addition to PCA and regression analysis.

The utilization of data mining was preferred as it generally permits to identify relations without apriori assumptions. Chávez, Jorge et. al. [18] also utilized data mining as a tool

to deduce socio-economic perspectives which could affect the relationship between students and their corresponding teachers. Another study was also done utilizing the same tool; Hela Ltifi et. al. [19] utilized data mining to represent data visually. The aim of this study was to detect patterns that doctors rely on to help make dynamic decisions regarding infections in a hospital. Similarly, we have utilized data mining as a tool to help us derive a well-organized and more precise study regarding the effects of socio-economic factors on scientific thinking.

3. FEATURES AND PREPROCESSING

A. Features, Feature Types and Possible values

The 408 records were analyzed upon 2 groups of features in which these 2 groups poses a total of 71 sub-features. The first group holds 4 main features of which they reflect the demographical information about a particular students.

These features are:

1. SED: This feature specifies the socio-economical level of the subject. It takes a numeric value between 1 and 3. These values are enumerated according to the given answers:
 - 1: Monthly income of the subject is less than 2000TL
 - 2: Monthly income of the subject is between 2000TL and 4000TL
 - 3: Monthly income of the subject is more than 4000TL
2. GENDER: Sex of the subject. This feature consist of 3 different values:
 - 1: Male
 - 2: Female
 - Null: Missing value
3. M_EDU: Education level of the subject's mother. It takes a numeric value between 1 and 5. These values are enumerated according to the given answers:
 - 1: Illiterate
 - 2: Primary School graduate
 - 3: High School graduate
 - 4: University degree graduate
 - 5: Master/Doctoral graduate
 - Null: Missing value
4. F_EDU: Education level of the subject's father. Same feature information type with M_EDU.

The 2nd group of features consists of 67 sub-features in which these 67 sub-features are divided upon the 4 psychological tests mentioned below. The numbering is based on test acronyms and feature within these tests. These tests' answer values are numerical and they can range between 1 which reflects "strongly agree" to 5 which

reflects “strongly disagree”. These tests with their according features are listed below:

- AT1..AT12 : Attitude test towards school.
- AK1..AK30 : Academic support test.
- AS1..AS5 : Academic satisfaction scale.
- SC1..SC20 : Scientific thinking skills test.

B. Preprocessing and verification

The preprocessing and verification stage aims to validate the data given by the student through the utilization of JavaScript as mentioned above to check for semantic errors. Regarding syntax error, the values were controlled if they were in range. That is if the values were out-of-range, these out-of-range values were pushed in a proper list and the expert in charge was notified to retake the correct value from the physical test papers. As for fraud answers, the values given by each student were related with other values which should have been related together. If the expected related values were found in conflict, this indicated that the student didn't read the question and randomly answered the question and in this case these conflicting answers were marked as invalid for further analysis.

C. Extraction and Inversions

Before extracting the data and in order to generate aggregate features for each test group, each feature was examined and its coefficient factor was checked to be between a range of 1 or -1. This coefficient was calculated such that if the question was positively correlated with the value given by the student, it was given the coefficient of 1 otherwise the given coefficient was -1. For more details, we consider the following example which correlates the attitude with respect to the school:

“I think that the school is a necessity for every individual.” This proposition was positively correlated; on the other hand, “I think school is a waste of time.” was negatively correlated sentence in terms of the attitude towards the school. Results of the negatively correlated sentences were inverted as follows:

“1” was replaced with “5”, “2” was replaced with “4”, “4” was replaced “2” and “5” was replaced with “1”.

Semantically inconsistent results were replaced as missing values because of their worthless meanings for the research result. At last, the gender feature was assigned numerical values with respect to the student's choice for possible regression and correlation analysis purposes. As a conclusion we ended up all with all the extracted features to have numerical values assigned to them respectively.

D. Handling Missing Values and Invalid Data

%2 of the records (8 students) contained missing values. Another %1 of the data (4 students) contained invalid values. Since invalid results are also intersect with missing valued records by %2 (8 students), all of these records %3

(12 students) are completely ignored during analysis step for the sake of model accuracy. Dataset remained as 396 instances.

4. ANALYSING DATA

Simple statistics are applied on feature values to detect any abnormal distribution or invalid ranged values as shown in Figure 5.

Row ID	D SED	D M_EDU	D F_EDU	D AT1	D AT2
Minimum	1	1	2	1	1
Maximum	3	5	5	5	5
Mean	1.992	3	3.449	3.134	2.119
Std. deviation	0.843	1.13	0.869	1.191	1.069
Variance	0.711	1.276	0.754	1.417	1.143
Overall sum	789	1,188	1,366	1,241	839
No. missings	0	0	0	0	0
Median	?	?	?	?	?
Row count	396	396	396	396	396

Figure 5. Simple statistics showing no abnormal distribution or values.

For each psychological test a new aggregated feature was generated accordingly which demonstrated the sum of that particular test result. These calculated features and their description are listed below:

- AT_SUM: Summation of attitude test features values.
- SC_SUM: Summation of scientific thinking skill test features values.
- AK_SUM: Summation of academic support test features values.
- AS_SUM: Summation of academic satisfaction scale feature values.

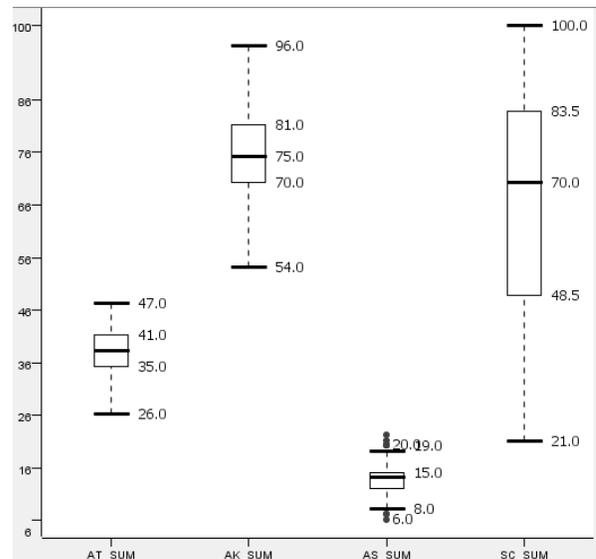


Figure 6. No conflict in answers though academic support test has 6 outliers.

Since the aim of this project was to predict which features affects the scientific the thinking skill set. It was noticed that the SC_SUM feature was the most dominant in that case. Figure 6 shows outlier detection represented as box plot through its newly aggregated feature set. Result of this analysis shows that there were some outliers (6 students) on academic support test. Since invalid or conflicting answers are omitted from the records, answers of these students are verified.

Correlation analysis was also done on aggregated features and demographical features. According to the correlation matrix on Figure 7 significant correlations have been found:

- Socio-economic status was negatively correlated with academic support test by -0.61.
- Mother’s education status was positively correlated with scientific thinking test by 0.72.

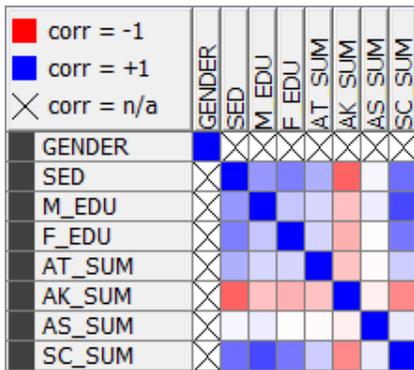


Figure 7. SED vs. AK_SUM is negatively correlated, M_EDU vs. SC_SUM is positively correlated.

1) *Segmentation and Clustering:* To detect different scientific thinking groups, k-means algorithm was used with k=7 and the normalized sum of the scientific thinking test result. Table 1 shows the clusters details for the related algorithm. The reason that k was selected to be 7 was indue that SC_SUM feature distribution shows that there are almost 7 distinguishable segments in 2D scatter plot.

TABLE 1. CLUSTER DETAILS FOR SC_SUM FEATURE

Cluster	Coverage	Value
Cluster_6	99 instances	1.13
Cluster_0	94 instances	0.58
Cluster_1	44 instances	0.03
Cluster_5	36 instances	-0.33
Cluster_3	31 instances	-0.67
Cluster_2	36 instances	-1.15
Cluster_4	56 instances	-1.68

Figure 7. K-means algorithm; clusters are ordered high test scored segments to lower ones.

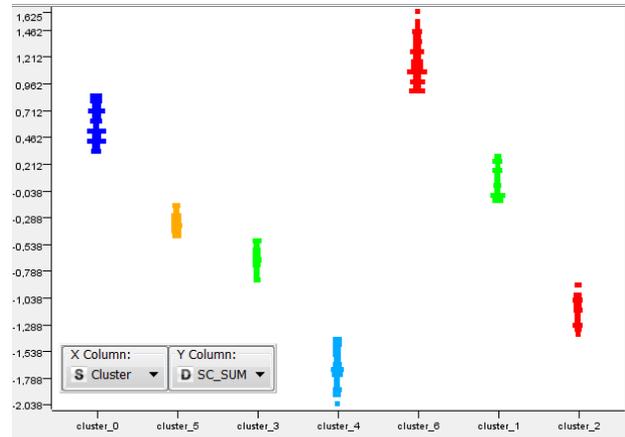


Figure 8. Segments representing different test scored students on scientific thinking skill clustered with k-means.

In addition, these segments were successfully identified with k-means algorithm (Figure 8) and therefore seven different type of students were identified with different scientific thinking skills.

2) *Decision Tree Analysis:* To analyse the relation of the clusters with respect to the students demographical information, J48 decision tree was used. J48 decision tree is an open source Java implementation of C4.5 algorithm in the weka data mining tool. Clusters were used as target features, whereas demographical features were used as deciseve features.

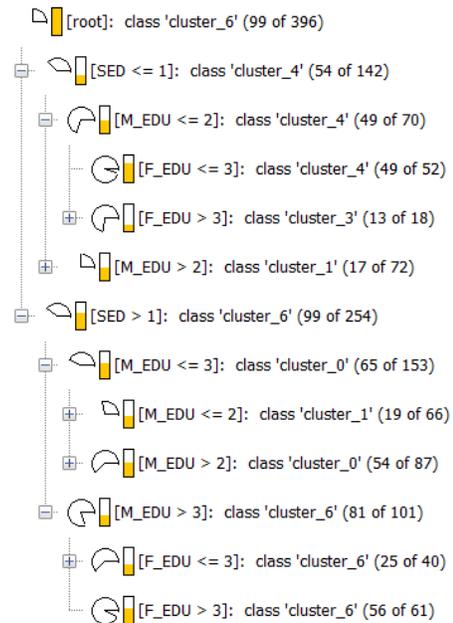


Figure 9. First level representing socio-economic status, second level is mother education level, third level is father education level of scientific thinking cluster.

Decision tree illustrated a useful pattern by separating the clusters according to their level. Figure 9 shows the tree result. According to results, gender had no influence on the results. The socio-economic level of the subject had the most dominant impact because it was realized in the first level of the decision tree, the most lower valued segment (cluster 4) and most higher valued segment (cluster 6) were separated. Another significant observation was the second and third level of separation which are mother education status and father education status, had also the same correlation effects on different sub nodes. For instance high mother education status values were proportional to the separation for the higher scientific skilled cluster. This shows that both of these features were directly influencing the subjects' scientific thinking results. 10 random sampling was done by splitting training and test data to test the decision tree model for the decision tree, model results seized to change.

3) *PCA Analysis*: To search whether is it possible to find pattern of scientific thinking test result from variability between other test results, AT_SUM, AK_SUM, AS_SUM features are used in PCA analysis. 3 PCA dimensions were observed and variability between these test results are reflected in 2D plot as shown in Figure 10. Further more, regression analysis was done on these PCA dimensions to predict scientific thinking test results. Therefore SC_SUM feature was selected as a target feature.

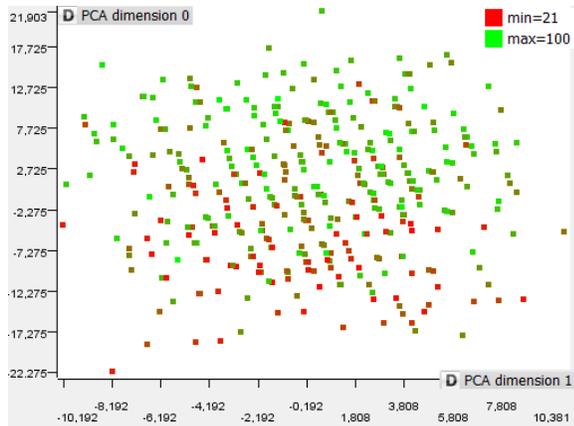


Figure 10. Variability between test results indicating the change in scientific thinking test results.

4) *Regression Analysis*: PCA analysis resulted 3 PCA dimensions which were new features extracted from dataset. These features were plugged in a 2nd degree polynomial regression model as shown in Table 2 to find the effect of predicting scientific thinking test results. The accuracy of this regression model is calculated by finding prediction errors as shown in Table 3.

TABLE 2. REGRESSION MODEL PARAMETERS FOR PCA FEATURES

Attribute Name	Intercept	Coefficient (x)	Coefficient (x ²)
PCA dimension 0	65.47	1.21	-0.03
PCA dimension 1	-0.02	0.26	0.04
PCA dimension 2	0.03	0.45	0.07

Squared error (per row): 352.53

TABLE 3. PCA REGRESSION MODEL PREDICTION ERRORS

Parameter	Prediction Error	Prediction Error Rate
Minimum	0.05	~0%
Maximum	45.50	56.05%
Mean	15.72	19.65%

To test the accuracy of another regression model, another different 2nd degree polynomial regression model was utilized. This model found the parameters shown in Table 4. Interestingly this model gave exactly the same accuracy results in Table 3 which reflects the prior PCA analysis results.

This result showed that PCA features derived from a given feature set does not affect the regression model accuracy as long as feature size is equal. Because there exist same amount of data to be explained through the variability of the target feature, PCA transformation does not seem to affect the prediction.

TABLE 4. REGRESSION MODEL PARAMETERS FOR PSYCHOLOGICAL TEST FEATURES OTHER THAN SCIENTIFIC THINKING SKILLS

Attribute Name	Intercept	Coefficient (x)	Coefficient (x ²)
AT_SUM	32.48	-1.72	0.03
AK_SUM	0.03	2.85	-0.03
AS_SUM	-0.03	-1.64	0.08

Squared error (per row): 352.75

Finally, regression analysis was done for each individual 47 feature that resembled the psychological test questions. In this case, the target feature was selected as to be aggregated sum of the scientific thinking skill feature. This analysis done on 2nd degree polynomial regression model which gives the best result as shown in Table 5 which reflects the expanded prediction range by %20 and the mean error decrease by 4% percent.

TABLE 5. TEST FEATURES EXCLUDING SCIENTIFIC TEST FEATURES REGRESSION MODEL PREDICTION ERRORS

Parameter	Prediction Error	Prediction Error Rate
Minimum	0.03	~0%
Maximum	50.44	63.05%
Mean	12.43	15.53%

5. RESULTS AND INTERPRETATION

In order to put into perspective of the study a brief comparison with the previous related work is given in Table 6. In our study, clustering, decision tree, correlation matrix, and regression analysis are used to investigate how the scientific thinking skills are related with the other features.

The correlation matrix showed that:

- Socio-economic status was negatively correlated with academic support test by -0.61.
- Mother's education status was positively correlated with scientific thinking test by 0.72.

To further analyze these results, segment clustering was done on scientific thinking skill results and decision tree was used to examine separation patterns of these clusters. From decision tree it is deduced that:

- If the socioeconomic status of the student is middle in level scientific thinking increases, whereas low socioeconomic status had negative effects on scientific thinking values.
- Parent's educational status effects positively the scientific thinking skills.

According to the domain expert, these results were expected and they have shown that factors like attitude toward school, scientific thinking, socioeconomic level and parent's level of education are all interconnected.

To understand how the psychological tests affect the scientific thinking skills, regression and PCA analysis was done on the dataset. These analyses showed that scientific thinking skills changed with the following:

- High attitude test results showed positive effects on scientific thinking skills.
- High academic satisfaction showed positive effects on scientific thinking skills.

According to the domain expert, these results were expected in terms that attitude towards school is a determinant factor for scientific thinking skills. Individuals with positive attitudes toward school are those with higher levels of scientific thinking. This was due to positive educational support, having good scientific role-models in the educational process, or having good mentors.

Attitude toward school includes general beliefs in the necessity of school in one's life in order to develop. These beliefs are shaped during the early years of life especially by the attitudes of the parents towards their children's education. The more the parents- especially the mother as the first hand care-giver- contribute to their children's educational process, the more positive attitudes toward school can emerge. Parental contributions are seen also to be related to the socioeconomic level of the family which is determined by both the income and the educational level.

Concerning academic satisfaction, subjects from high socioeconomic level families may have higher scientific thinking skills due to their living conditions. Socioeconomic status includes both education and income of the family. Therefore, high socioeconomic level families offer their children better chances for education, recreational activities and a better open insight to cultural background. In an average Turkish university, expectations of students from high SES families may not be fulfilled, thus it may lead to lower levels of academic satisfaction. In other words, students from high SES families may be frustrated through thinking that they are not being supported well enough by their academic atmosphere. This is due that the level of service quality being less compared to the support of the family.

On the other hand, students from low socioeconomic level families are those who have low levels of guidance. This is due to lower levels of income and education of the family. They are not familiar with good role models or mentorship during their educational history. Thus, their schemes about school are not strong enough to shape a concept about future education. Therefore, it's not a surprise to have negative correlations between socioeconomic level and academic satisfaction. The middle socioeconomic level students were said to be with a particular educational support, a better vision for future, as well as adaptive capabilities to the environmental support.

The presented study demonstrates the effects of factors such as attitudes, socioeconomic level and parent education on scientific thinking, academic satisfaction and academic support. Students' perceptions of academic support and expectations from school may depend on their cultural background and the family's socioeconomic level.

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Reference	Method	Dataset Characteristics	Main Result(s)/Finding(s)
Ref [8]	Images and questions were utilized as a technique to conduct the study	3rd and 4th graders were selected from different schools	Socio-economic factors do contribute to critical thinking which was especially realized when it came to selecting rich schools were the socio-economic factors are nearly the same
Ref [9]	Cornell Critical Thinking test is utilized but it was found not suitable to measure the multifaceted thinking for engineering students	1st year engineering students from a certain school	Time series methodology with critical Value rubric was utilized and then appropriate conclusions were made with respect to the value rubric.
Ref [10]	Mapping between practice and critical thinking and the assessment was made through Critical Thinking in Midwifery (CACTiM)	Midwifery and nursing undergraduates in a certain school	Midwifery showed high level of critical thinking relating the critical thinking to practice thus the success of the test as a whole
Ref [11]	Students were asked to write their thoughts about certain topics and this process was repeated twice.	Chemical and biochemical students from a certain school	The thoughts were recorded and furthermore compared with previous years thoughts. The results confirmed that the level of critical thinking is directly influenced on daily activities stated by the author
Ref [12]	A survey was conducted with high level questioning. In addition a Focus Group Decision groups was also utilized which was also used for later assessments	39 Korean students were selected to conduct the test	The test holders were feeling discomfort about the communicative activities which ensures that the level of critical thinking is related to the way to communicate information and the language abide by it
Ref [13]	Critical Thinking Attribute Survey (CTAS) was utilized	120 students were selected in this study from a certain school	More than 50% of the total responses were marked as high for sciences which ensures that sciences as a material taught in schools has a lot of influence in increasing the level of critical thinking
Ref [14]	The author emphasis that the foreign students coming to England to pursue studies have problems to express their critical thinking level due to language and writing deficiencies		The author advises the students who wish to come to UK for further studies to take online courses that will help them with the deficiencies with respect with the language and the writing criteria needed
Our study	Data mining, clustering , data segmentation, PCA and regression analysis was utilized in our study	408 undergraduate students in Akdeniz University (Turkey)	The results show that socio-economic factors taken into consideration has direct influences on the level of critical thinking expected from the students during the university domain.

TABLE 6. A BRIEF COMPARISON WITH PREVIOUS STUDIES

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