Innovative Pedagogical Models for Teaching R Software: SPS Approach and a Proposed Application

R Yazılımı Öğretimi için Yenilikçi Pedagojik Modeller: SPÇ Yaklaşımı ve Önerilen Bir Uygulama

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ABSTRACT

R is widely used for tasks such as statistical computations, data analysis, and visualization. As R software is open-source and free, its teaching is becoming increasingly popular in higher education. Recently, courses on R software have been incorporated into master's and doctoral programs. The Selective Problem Solving (SPS) model is a novel approach to creative problem-solving in mathematics education, based on mathematical problem-solving models, insightful thinking theories, and creativity research. It involves six sequential steps: defining the target problem, identifying the source problem, solving the target problem, creating an original problem, solving the original problem, and concluding with an evaluation. This study explores the theoretical framework of the SPS model and its application in teaching the R programming language. It specifically demonstrates the SPS model's use in selecting desired elements within matrices using R. The implementation is detailed through sub-steps and illustrative examples. Anticipated contributions include enriching content and fostering differentiation for educators teaching R. This study underscores the SPS model's viability as a teaching tool for R and suggests future exploration of its use for teaching various R-related subjects, as well as examining the overall efficacy of R instruction facilitated by the SPS model. In practical application, instructors may face challenges such as ensuring correct analogical transfer, maintaining student engagement across all SPS steps, and addressing diverse prior knowledge levels in R programming and matrices. The SPS model can be particularly effective in disciplines that involve structured problem-solving, including data science, statistics, engineering, and computer science courses. Future research could explore its application to additional R-related topics and empirically evaluate its effectiveness.

Keywords: Creative problem solving, pedagogical framework, R programming education, selective problem solving model.

ÖZ

R, istatistiksel hesaplamalar, veri analizi ve görselleştirme gibi çeşitli veri analizi görevleri için kullanılmaktadır. R yazılımı açık kaynaklı ve ücretsiz olduğundan, yükseköğretimde R öğretimi giderek daha popüler hale gelmektedir. Son yıllarda, R yazılımının öğretimi ile ilgili dersler yüksek lisans ve doktora programlarında kendine yer bulmaya başlamıştır. Seçici Problem Çözme (SPÇ) modeli, matematik eğitiminde yaratıcı problem çözmeye yönelik yeni bir yaklaşımdır ve matematiksel problem çözme modeli, iç görüsel düşünme teorisi ve yaratıcılık araştırmalarının temellerine dayanır. Altı ardışık

adımdan oluşan SPÇ modeli, hedef problemi tanımlama, kaynak problemi tanılama, hedef problemi çözme, orijinal problem oluşturma, orijinal problemi çözme ve değerlendirmeyi içerir. Bu çalışma, SPÇ modelinin teorik çerçevesini incelemekte ve R programlama dilinin öğretimindeki bir uygulamasını açıklamaktadır. Spesifik olarak makale, R yazılımını kullanarak matrisler içinde istenen öğeleri seçme sürecini öğretmede SPÇ modelinin kullanımını göstermektedir. SPÇ modelinin R öğretiminde uygulanması, alt adımlara odaklanılarak açıklanmış ve açıklayıcı örneklerle desteklenmiştir. Bu araştırmanın beklenen katkıları, R öğreten eğitimciler için içerik oluşturmayı zenginleştirmeyi ve farklılaştırmayı teşvik etmeyi kapsamaktadır. Bu çalışma, SPÇ modelinin R için bir öğretim aracı olarak uygulanabilirliğinin altını çizmektedir. Gelecekte yapılacak olan çalışmalarda bu model R öğretiminin farklı konularında kullanılabilir, SPÇ ile yapılan R öğretiminin etkililiği incelenebilir. Pratik uygulamada, eğitmenler doğru analojik aktarımın sağlanması, tüm SPÇ adımlarında öğrencilerin ilgisini canlı tutma ve R programlama ve matrisler konusunda farklı ön bilgi düzeylerine sahip öğrencilerle başa çıkma gibi zorluklarla karşılaşabilirler. SPÇ modeli; veri bilimi, istatistik, mühendislik ve bilgisayar bilimi dersleri dahil olmak üzere yapılandırılmış problem çözme içeren disiplinlerde özellikle etkili olabilir. Gelecekteki araştırmalar, modelin R ile ilgili diğer konulara uygulanmasını keşfedebilir ve etkinliğini ampirik olarak değerlendirebilir.

Anahtar Kelimeler: Yaratıcı problem çözme, pedagojik çerçeve, R programlama eğitimi, seçici problem çözme modeli.

INTRODUCTION

The introduction of this study is presented under three subheadings. Each sub-heading contains relevant information. These subheadings are as follows: Introduction to R Programming, Theoretical Foundations of the Selective Problem Solving (SPS) Model, and Applications and Literature Review of the SPS Model in Education.

1.1. Introduction to R Programming

R is an open-source programming language used for various data analysis tasks such as statistical computations, data analysis, and visualization. It offers a wide range of tools for performing statistical calculations and creating graphics. The history of R software traces back to the S project initiated at Bell Labs in 1976, which evolved into a general licensed system by the 1980s. Today, R, managed by the R Foundation for Statistical Computing, is widely utilized not only for statistical computations but also in fields such as data analysis, machine learning, and big data processing (Chambers, 2009). Among the advantages of R are its cost-free nature, extensive library for statistical computations, and specialized application packages for a wide range of statistical and mathematical methods (Pravilovic, 2013). However, there are also disadvantages to using R, including the necessity for new users to learn a new programming language, challenges in handling missing data, and limited support and documentation (Culpepper & Aguinis, 2010). The flexibility and broad applicability of R software have rendered it a favored tool among researchers across various disciplines. Researchers have embraced R as a dependable instrument for data analysis, statistical modeling, and effective visualization of results. Particularly within the field of educational sciences, the use of R in data analysis has become widespread.

In recent years, courses related to the instruction of R software have found their place in the master's and doctoral programs in measurement and evaluation within universities in Turkey. For instance, Ankara University's Educational Measurement and Evaluation master's program includes a course titled "Classical Test Theory and R Applications". The aim of this course is defined as introducing R software and guiding learners on how to use R for statistical data analysis (Ankara University, 2024). Another example is the "Statistical Programming in R" course in the Educational Measurement and Evaluation master's program at Gazi University. The aim of this course is to provide an introduction to data processing, transformation, coding, visualization, exploration, basic statistical calculations, and summarization using the R

programming language. Additionally, it aims to equip students with programming skills in R to apply commonly used statistical methods in the fields of education and psychology (Gazi University, 2024). It is expected that the teaching of R will become more widespread in other graduate education programs in the coming years.

1.2. Theoretical Foundations of the Selective Problem Solving (SPS) Model

The concepts of problem and creativity have been defined differently because they are abstract concepts. The concept of the problem is generally used to describe disturbing situations. The concept of creativity was defined by Torrance (1967) as being sensitive to situations such as problems and uncertainties. Guilford (1975) interpreted creativity as a form of problem-solving. According to this, there are four primary problem-solving abilities: sensitivity to the problem, fluency, flexibility, and originality (Guilford, 1975). The Selective Problem Solving (SPS) model was developed by Sak (2011) and used in teaching creative problem-solving skills. The SPS model was created based on a mathematical problem-solving model (Polya, 1957), insightful thinking theory (Davidson & Sternberg, 1984), and creativity research.

According to Polya (1957), the mathematical problem-solving model; consists of four stages: understanding the problem, devising a solution plan, carrying out the plan, and looking back. In understanding the problem stage, all the information in the problem is identified. In devising a solution plan stage, a plan is developed by evaluating various solutions and perspectives that can be used in solving the problem. In carrying out the plan stage, the plan is put into effect. The problem-solving process is evaluated by checking the correctness of the solution during the looking back phase. In the theory of insightful thinking, there are three concepts: selective encoding, selective combination, and selective comparison (Davidson & Sternberg, 1984). Selective encoding means distinguishing necessary information from unnecessary information in problem-solving. Selective combination means bringing together related ideas to solve the problem. Selective comparison means comparing new and old information by establishing similarities. According to creativity studies, problem definition, problem identification, and problem construction are more critical than problem-solving, and these concepts form the roots of creative problem-solving (Runco, 2006). In the problem definition step, all parts of the problem are coded, and all components of the problem are tried to be understood. In the problem identification step, the problem is re-stated in detail. The problem construction step can occur before, in, and after the solution (Silver, 1994).

1.3. Applications and Literature Review of the SPS Model in Education

Since SPS is a newly developed model, the number of studies on this model in the literature is minimal. When the applications of the SPS model in education are examined, it is seen that there are studies in which the social validity of the model is tested (Bal-Sezerel & Sak, 2013; Karabacak & Kirişçi, 2019). According to the findings of these studies, the social validity of the SPS model and the satisfaction levels of the participants with this model are high. In another series of studies (Kirişçi et al., 2020; Manah et al., 2017; Pambudiarso et al., 2016; Widiyanto et al., 2022; Zaenuri et al., 2019), it is seen that the effectiveness of the SPS model was evaluated in the context of mathematics teaching. It was concluded that the SPS model was effective in all of these studies. Endardini (2017), on the other hand, concluded that the SPS model positively affected the variables of high-level thinking skills and created a positive perception of mathematics. In another study, Kılıç and Ayas (2017) focused on adapting the SPS model to science. In this study, the importance of the SPS model for science is emphasized, and the SPS model in science is explained with examples. Finally, Kirişçi (2021) examined the SPS model with the literature review method. This study discussed the model in detail with a problem used in teaching mathematics.

IMPLEMENTING THE SPS MODEL IN R PROGRAMMING EDUCATION

This section of our study investigates in instructing the process of selecting desired elements within matrices in R software through the lens of the sub-steps outlined in the Selective Problem Solving (SPS) model. Assuming familiarity with R software vectors among students, we employ the SPS model as a guiding framework. The SPS model comprises six sequential steps: defining the target problem, identifying the source problem, solving the target problem, creating an original problem, solving the original problem, and evaluating (Sak, 2011). Within this section of our study, we elucidate the application of the SPS model in teaching R, emphasizing its sub-steps with practical examples.

2.1. Defining the Target Problem

At this step, the components of the problem are coded, and the relationships between the components are tried to be understood (Sak, 2011). Coding can be done as a process and selective coding. In process coding, all components of the problem are coded. In selective coding, the information required for problem-solving is coded by distinguishing it from others (Davidson & Sternberg, 1984). At this step, students are expected to explain the known and unknown components of the problem. In this step, teachers use questions such as: "What is the problem?", "What is known about the problem?" and "What are the unknowns in the problem?". Thus, they ensure the active participation of students in the process. The target problem should be such that it answers these questions, is challenging for the students, that the students have not encountered before, and that the students can use their previous learning (Sak, 2011). The sample target problem of the instructing the process of selecting desired elements within matrices in R software is shown in Figure 1.

Figure 1

Sample Target Problem

```
> data<- rnorm(100,mean=0,sd=1)
> matrix<- matrix(data=data, nrow = 10, ncol = 10, byrow = TRUE)
> matrix
            [,1]       [,2]       [,3]       [,4]       [,5]       [,6]       [,7]       [,8]       [,9]      [,10]
 [1,]  1.8204731 -0.5947976 -0.34901873 -0.937159362 -0.83206066  0.32245861  0.34860345 -0.01391047  0.308954635 -1.31932212
 [2,]  0.1500723 -1.7366532 -0.41641695  0.574082198 -0.68208137  1.47569132  0.98501672  1.05022740  0.562201426 -0.05059373
 [3,]  0.3177092  1.1840871 -1.47892394  0.287230156  1.30321783 -1.24019530  1.54647069  0.71924442  1.337269926  0.70205021
 [4,]  0.2282035  0.9795788 -1.70353277  0.032469551 -0.01906427  0.09360357  0.36516587 -1.12615714 -0.317330211 -2.01480652
 [5,] -0.1403580 -1.6642434 -0.14778687  0.188932091 -0.71132706  0.57771266 -0.06644071  0.41160570  0.761919548  0.10574337
 [6,] -1.4720143 -0.8167941  1.09120924 -1.509969151  0.50008412 -0.90718138 -0.23419227 -0.83487192 -1.266253212 -0.71085080
 [7,] -0.1785547  1.0402742  1.10345179  0.380809423  0.20627443 -0.68328726  0.17297237 -0.02058059  1.200189560  2.29291545
 [8,]  1.6601038  0.3198218  0.08126222 -1.588921983  0.34435758 -0.40520963 -0.53052618  0.46427249  1.600369068  1.27978991
 [9,]  1.7074260 -0.6857655 -1.33046951 -0.001512071 -1.45704386 -0.52386297  1.69453665  1.63776003  0.008379474  0.14710102
[10,] -0.1414469  1.2447474 -0.23371166 -0.537827998  0.70309689  1.47496760  0.63642498 -1.26127079  0.319257745 -0.14272048
> ### Question: According to the data set above, what does the "matrix[7,5]" code do and what is the output of this code?
```

When the sample target problem was examined, the students were asked to explain what the "matrix [7,5]" code does and what the output of this code is, according to the data set in the figure. While creating the data set for the target problem, some procedures were followed in the R software. First, the code "data<- rnorm(100, mean=0, sd=1)" was used by the researchers. This code ensures that 100 measurements are randomly drawn from a normal distribution with a mean of zero standard deviation of one and saved in a vector named "data". Then, a matrix was generated using the code "matrix<- matrix (data=data, nrow = 10, ncol = 10, byrow = TRUE)" from 100 measurements in this vector named "data". This code ensures that all elements in the vector named "data" are transferred to a 10x10 type matrix with 10 row and column numbers, and all these operations are recorded in a matrix called "matrix".

The target problem in Figure 1 is a challenging problem for graduate students taking this course for the first time and new to matrices. However, it is a sample problem that they can connect with their previous learning. Students have previously learned to perform operations related to vectors in R software. Vectors are unidirectional because they do not contain columns

in the data set. Matrices, on the other hand, are bidirectional because they contain rows and columns. Students know that square brackets draw a desired element in vectors. For example, students know that the "data [5]" code is used to draw the fifth element in a vector named data and will output the fifth element of the data set. The "matrix [7,5]" code in the target problem in Figure 1 is used to select the element at the intersection of the seventh row and fifth column of the matrix named matrix. In this context, students are expected to transfer the knowledge learned in vectors to the target problem.

2.2.Identifying The Source Problem

At this step, students are asked to make selective comparisons between the problems and establish a similarity between the target and the source problem. Analogies are used in selective comparison. The target problem should contain some clues for students to make an analogy. In this step, students either identify an analogous problem or choose the problem that they can make an analogy with from the given source problems. Teachers try to make students produce analogical problems using questions such as "Have you encountered this problem before?" and "Have you encountered another similar problem?". Teachers use questions such as "Which problem is similar to the target problem?", "In what ways do you think this problem and the target problem are similar?" and "In what ways are the unknowns of this problem and the target problem similar?" so that students can choose the appropriate analogical problem (Sak, 2011). The sample source problems of the instructing the process of selecting desired elements within matrices in R software are shown in Figure 2 and Figure 3.

Figure 2

Sample Source Problem 1

```
> data<- rnorm(100,mean=0,sd=1)
> data
  [1] -1.05148418  0.75983193 -1.13434990  0.58143560  0.54220182  0.28364067 -0.70357953 -0.38726378 -0.87212394 -0.72772722
 [11] -0.34892567 -0.38344376  1.89920930  0.22907405 -0.75847296 -0.96917341  0.11785257  0.75685209 -0.51572715  1.60387847
 [21] -1.03605210 -1.01060862  0.34510893  0.45087766 -0.31729159  1.24440793  0.56101606 -0.91893672  0.52262564 -0.89677962
 [31] -0.72645929  1.23120806 -1.18507030  2.04023189 -0.81226444 -0.80853264  0.28383097 -0.42597854  1.36732858  0.61300557
 [41] -2.11460070 -0.45446416 -1.56541336  1.33674409  0.76503237  0.83257202 -0.88160454 -1.60748675  0.22364133 -0.16833799
 [51] -0.65335418 -0.58237481  0.69855259  0.32701807  0.77064756  1.41417994  0.58712279  1.13146284  0.98811675 -0.22319036
 [61]  2.52364265  0.38761739 -0.05440635 -1.28634168  0.76488539  1.56394887  0.30857094 -0.40753183 -1.64041852 -0.08456771
 [71]  0.46252261 -2.04223154  0.57893330  0.22137727  0.95605954 -0.11959851 -1.16079751  1.99557595 -0.54212664  0.27553956
 [81] -0.25701608 -1.10491199  0.17535616 -1.27275833 -0.40022237 -0.29861978 -3.62908651 -0.43641311  1.41829494 -0.06445346
 [91]  0.51437083 -0.58361277  1.87718352  0.68319230  0.03970473 -1.23108983  0.90764242  1.44721514 -1.33430860 -1.00033695
> ### Question: According to the data set above, what does the "data[10]" code do and what is the output of this code?
```

Figure 3

Sample Source Problem 2

```
> data<- rnorm(100,mean=0,sd=1)
> data
  [1]  0.42632025  0.24026517  1.17483196  1.41628774 -0.34871693 -1.19923699  1.31492790 -0.72335282  1.15184251 -0.50326381
 [11] -2.18376951 -0.51702706 -0.90963329  0.44865665  0.92600104 -1.44466973 -0.16778646 -0.37526003  0.24956609 -1.99612010
 [21]  0.73571461 -0.48992265  1.00659427  0.94208918  1.62305333 -0.10323396 -2.61439976 -0.21412943  1.71005671  0.58249145
 [31] -0.55570532  1.06161762  1.08906788 -2.77345622  0.39700116 -0.38486115 -0.47401081 -0.96537878 -0.23135244 -0.59420050
 [41]  0.69014201  0.92590138 -0.18259576 -0.78211997  0.71729697 -0.53255647  1.08734389 -0.91035471  0.83628204 -0.01055931
 [51]  1.91896361  0.18821888  0.94850082  0.22750572 -0.93169553  0.03301604  0.73582662  0.59821655 -0.87439818  2.00061447
 [61] -0.37867812 -1.79804210 -0.55498086  0.65841692 -1.86521801 -0.13479294  0.25119154  1.02629626  0.08910984 -0.26793395
 [71] -1.19768552 -1.80405841 -0.46303604 -1.22245578 -0.53031037 -0.25553124  1.30693217  0.23201871  0.40854572  1.90286498
 [81]  0.05920284 -0.97663870 -0.36626796  0.48269707 -0.60331541 -0.24518304  1.27789788 -0.08566643  0.91632121 -0.20623745
 [91] -1.31736262 -0.66590581 -0.72637377 -0.09442304  0.73074851 -0.35231713  2.02703002  0.60698929  0.44419138  1.01556404
> ### Question: According to the data set above, what does the "data[1:10]" code do and what is the output of this code?
```

When the sample source problems were examined, the students were asked to explain what the "data [10]" and "data [1:10]" codes do and what the outputs of these codes are, according to the data sets given in the figures. While creating the data sets in the source problems, the code "data<- rnorm(100, mean=0, sd=1)" was used in the R software by the researchers. This code ensures that 100 measurements are randomly drawn from the normal distribution with a mean of zero standard deviation of one and saved in a vector named "data". The datasets differ because this code was run separately for the two source problems. Each time

the code is read into the R software, it randomly pulls 100 measurements from the normal distribution.

The "data [10]" code in the sample source problem in Figure 2 provides the tenth element in a vector named data and gives the value "-0.73", which is the tenth element of the data set. The "data [1:10]" code in the sample source problem in Figure 3 allows us to draw all the elements from one to ten in a vector named data. This code outputs the values of "0.43, 0.24, 1.17, 1.42, -0.35, -1.20, 1.31, -0.72, 1.15, -0.50", which are all elements of the data set from one to ten. The "matrix [7,5]" code in the target problem in Figure 1 is used to draw a single element in the matrix. The "data [10]" code in the sample source problem in Figure 2 is also used to draw a single element in the vector. For this reason, the students are expected to establish a connection between these two problems. The situation that students are unfamiliar with in the target problem is that there is a comma in the "matrix [7,5]" code. Here, the number to the left of the comma represents the seventh row of the matrix, and the number to the right represents the fifth column of the matrix. The "data [1:10]" code in the second source problem is used to extract more than one element and differs from the source problem in this respect. For this reason, the students are expected to establish an analogy between the target problem and the first source problem.

2.3. Solving the Target Problem

At this step, students are expected to solve the target problem with the correct analogical transfer (Sak, 2011). The stronger the analogy between the source and the target problem, the stronger the analogical transfer. (Holyoak & Koh, 1987). The teacher tries to ensure that the students make the correct analogical transfer by using the "How can you use the solution method of the analogical (source) problem in solving the target problem?" question. After solving the target problem, the teacher tries to make the students check the solution process by asking, "How can you prove the correctness of the steps in problem solving?" (Sak, 2011).

In order to solve the target problem used in our study in Figure 1, students are expected to transfer the method they used to solve the sample source problem in Figure 2 to analogical transfer. The code in the sample source problem in Figure 2 is used to draw a single element, and the code in the sample source problem in Figure 3 is used to draw more than one element. Since vectors are one-dimensional, only one element in square brackets is in the "data [10]" code. Since matrices are two-dimensional structures consisting of rows and columns, two elements in square brackets in the "matrix [7,5]" code and commas separate these elements. The "data [10]" code in the source problem outputs the value "-0.73", which is the tenth element of the vector named data. Similarly, the "matrix [7,5]" code in the target problem outputs the value of "0.21", which is the element at the intersection of the seventh row and fifth column of the matrix named matrix.

2.4. Creating an Original Problem

At this step, students are expected to create an original problem similar to the target problem, more complex and challenging than the target problem. The teacher can use the "Can you write more advanced and more difficult problems than the target problem that you can solve using the methods you used to solve the target problem?" question to start the process. The teacher continues the process with the questions "What does this problem want from us?", "How are the solution methods of this problem and the target problem similar?" and "In what way is this problem more advanced than the target problem?" so that the students can express the similarities of the problems created by the students with the target problem. If the original problems created are unsuitable, the teacher presents the original problem to the students (Sak, 2011). The sample of the original problem of the instructing the process of selecting desired elements within matrices in R software is shown in Figure 4.

Figure 4

Sample Original Problem

```
> data<- rnorm(100,mean=0,sd=1)
> matrix<- matrix(data=data, nrow = 10, ncol = 10, byrow = TRUE)
> matrix
         [,1]       [,2]       [,3]         [,4]        [,5]        [,6]       [,7]        [,8]       [,9]        [,10]
 [1,] -0.7116757  0.6628620  2.21594174  0.007164014 -0.93576639 -0.19511356 -1.9803014 -0.18513683 -0.9521252 -1.023656447
 [2,]  1.7573227 -0.7499369  1.70675964  1.039804715 -0.67655736 -1.02025535 -0.3743932  0.22582128  0.4859108 -1.306564408
 [3,]  0.1675693  1.4621650 -0.63132137  0.070916575  0.80341465  0.80013071  0.9758958  1.09667830 -0.8467100  0.914784508
 [4,] -1.3584266 -0.3143044  0.34370928 -0.972865620 -0.30150781 -0.76564930 -1.0986060 -0.65072973  2.3218289 -0.441365516
 [5,]  0.8332144  0.2587417  0.19007092 -0.178912041  0.47972769  0.41445367  0.7502366  0.61731783 -0.6779033 -0.944807126
 [6,] -0.1477180  0.1971992 -1.23519409 -1.115834374  0.38995646 -0.05036474 -0.3596150 -0.01638595 -1.3014437  0.541773207
 [7,] -0.1237005  0.4668181  0.81974796  0.593604258  0.83464242  0.74223276  1.0289890 -0.72666407  1.4256211  0.056139519
 [8,]  0.8096516  0.7276176  0.88215261  1.076348155 -0.19280125 -0.26338075 -1.0942016  0.38869965  0.0396112  0.260643634
 [9,] -0.3425985  0.3621313 -0.61188081  0.743460564 -0.38670738 -0.78562199  2.0879625 -0.23202775  0.9091446  0.254630519
[10,] -1.0629165  0.8501122  0.09029264 -0.557592851  0.02461988  0.81701313  1.1256626  2.00712889 -1.9616267 -0.008194844
> ### Question: According to the data set above, what does the "matrix[3:6,2:5]" code do and what is the output of this code?
```

When the sample original problem was examined, the students were asked to explain what the "matrix [3:6,2:5]" code does and what the output of this code is, according to the data set given in the Figure 4. While creating this data set, the steps in creating the sample target problem in Figure 1 data set were followed. The sample original problem is similar to the sample target problem in that the dataset is a matrix and contains square brackets to pull the desired elements. The square brackets in the "matrix [3:6,2:5]" code indicate that some matrix elements will be drawn as in the sample target problem. The part where the sample original problem is more advanced and more complex than the target problem is that there is not one number on the right and left sides of the comma in the "matrix [3:6,2:5]" code. In the "matrix [7,5]" code in the sample target problem in Figure 1, the numbers to the left and right of the comma represent which element at the intersection of the row and column will be drawn. In the "matrix [3:6,2:5]" code in the sample original problem, the left of the comma represents rows three to six, and the right represents columns two to five. For this reason, when the "matrix [3:6,2:5]" code is run in R software, eight elements will be output at the intersection of four rows from three to six and four columns from two to five.

2.5. Solving the Original Problem

At this step, students are expected to solve the sample original problem in Figure 4 with the analogical transfer experience they have gained in solving the sample target problem in Figure 1. The teacher starts the process with the question, "How can you use the solution method of the target problem in solving the original problem?". The original problem must be created with a correct analogy. After the problem is solved, the teacher asks, "How can you prove the correctness of the steps in the problem solving?" to ensure that the students control the solution process (Sak, 2011). In order to solve the sample original problem in Figure 4, students are expected to transfer the method they used to solve the sample target problem in Figure 1. The "matrix [7,5]" code in the sample target problem draws a single element in matrices. This code outputs "0.21", the element at the intersection of the seventh row and fifth column. Similarly, the "matrix [3:6,2:5]" code in the original problem outputs the "1.46, -0.63, 0.07, 0.80, 0.31, 0.34, -0.97, -0.30, 0.26, 0.19, -0.18, 0.48, 0.20, -1.24, -1.12, 0.39" values, which are the elements at the intersection of rows three to six and columns two to five of this matrix.

2.6. Evaluating

At this step, students are expected to evaluate all stages of the problem-solving process and their experiences. The teacher starts the evaluation process with the question, "What did you learn while solving the problems?". The teacher enables the students to evaluate the process by using, "How did you use analogies while solving problems?", "How did you use analogies to create original problems?" and "How did you become selective when solving problems?" questions (Sak, 2011).

CONCLUSION AND RECOMMENDATIONS

The SPS model is a very new model based on the mathematical problem-solving model (Polya, 1957), insightful thinking theory (Davidson & Sternberg, 1984) and creativity research (Sak, 2011). In the literature, the studies in which the SPS model was a subject were mainly evaluated in the context of mathematics. Although this model is generally used to develop creative problem-solving skills in mathematics, Balsezerel and Sak (2013) state that this model can be adapted to other disciplines besides mathematics. In this context, a study in the literature by Kılıç and Ayas (2017) on adapting the SPS model to science. Apart from this study, no study was found in which the SPS model was adapted to other disciplines. In this context, our study is an original study adapted to instructing the process of selecting desired elements within matrices in R software.

Previous similar studies determined that the SPS model needed to be adapted to undergraduate or graduate courses or various disciplines. With our study, it has been shown with the examples that the SPS model can be adapted to graduate courses and other disciplines as well. Although the SPS model was developed for teaching mathematics, it can also be adapted for other disciplines like instructing R. Our study is expected to contribute to the instructors who instructing R in graduate courses in universities in terms of content creation and differentiation. It is also thought to contribute to the widespread use of the SPS model in other disciplines. In future studies, this model can be used for other subjects in instructing R, and adapted to different disciplines. The effectiveness of lesson plans prepared with the SPS model can be examined by applying the adapted lesson plans and taking pretest-posttest measurements with an experimental design.

In practical implementation, instructors may encounter challenges such as ensuring correct analogical transfer between source and target problems, maintaining student engagement throughout all six SPS steps, and addressing the varying levels of students' prior knowledge in R programming and matrices. Additionally, cognitive load may increase when students are asked to create original problems independently, which may require additional scaffolding from instructors. For practical use, the SPS model can be particularly effective in disciplines that involve structured problem-solving, including data science, statistics, engineering, and computer science courses. Instructors are advised to provide step-by-step guidance, illustrative examples, and incremental challenges when applying the model. Emphasis should be placed on supporting students' analogical reasoning, gradually increasing the complexity of original problems, and monitoring progress closely to ensure effective learning outcomes. Future research could explore the application of the SPS model to additional R-related topics, evaluate its effectiveness through empirical studies using experimental designs, and investigate ways to optimize the model for diverse student groups. Integrating digital tools to support the SPS steps may also reduce cognitive load and enhance the model's practical utility.

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GENİŞLETİLMİŞ ÖZ

Giriş

R, istatistiksel hesaplamalar, veri analizi ve görselleştirme gibi çeşitli veri analizi görevleri için kullanılan açık kaynaklı bir programlama dilidir. 1976'da Bell Labs'ta başlatılan S projesine dayanan R, 1980'lerde genel lisanslı bir sistem haline gelmiştir. R, İstatistiksel Bilgi İşlem Vakfı tarafından yönetilmekte olup, istatistiksel hesaplamalar, veri analizi, makine öğrenimi ve büyük veri işlemede yaygın olarak kullanılmaktadır (Chambers, 2009). Avantajları arasında maliyetsiz olması, geniş kütüphane desteği ve çeşitli yöntemler için özel paketler bulunması sayılabilir (Pravilovic, 2013). Dezavantajları ise yeni kullanıcıların dil öğrenme zorluğu, eksik verilerle başa çıkma zorlukları ve sınırlı destek/dokümantasyon içerir (Culpepper ve Aguinis, 2010). Eğitim bilimleri alanında da R'nin kullanımı yaygınlaşmış, üniversitelerin yüksek lisans ve doktora programlarında R dersleri yer almaya başlamıştır. Örneğin, Ankara Üniversitesi ve Gazi Üniversitesi'nde R yazılımını öğreten dersler bulunmaktadır.

SPÇ modeli, Sak (2011) tarafından geliştirilmiş ve yaratıcı problem çözme becerilerini öğretmekte kullanılmıştır. Bu model, matematiksel problem çözme modeli (Polya, 1957), içgörülü düşünme teorisi (Davidson ve Sternberg, 1984) ve yaratıcılık araştırmaları temel alınarak oluşturulmuştur. Polya'ya göre, problem çözme dört aşamadan oluşur: Problemi anlama, çözüm planı oluşturma, planı uygulama ve kontrol etme. İçgörülü düşünme teorisi, seçici kodlama, seçici kombinasyon ve seçici karşılaştırma kavramlarını içerir. Yaratıcılık araştırmaları, problem tanımlama ve yapılandırmanın problem çözmeden daha kritik olduğunu vurgular (Runco, 2006).

SPÇ modeline ilişkin çalışmalar sınırlıdır. Modelin sosyal geçerliliği ve katılımcı memnuniyeti yüksektir (Bal-Sezerel ve Sak, 2013; Karabacak ve Kirişçi, 2019). Matematik

öğretiminde SPÇ modelinin etkili olduğu çeşitli çalışmalarda gösterilmiştir (Kirişçi vd., 2020; Manah vd., 2017; Pambudiarso vd., 2016; Widiyanto vd., 2022; Zaenuri vd., 2019). Endardini (2017), SPÇ modelinin yüksek düzey düşünme becerileri üzerinde olumlu etkisi olduğunu ve matematik algısını pozitif yönde etkilediğini bulmuştur. Kılıç ve Ayas (2017), modelin fen bilgisine uyarlanmasını incelemişlerdir. Kirişçi (2021) ise modeli literatür taraması yöntemiyle detaylı olarak ele almıştır.

R Programlama Eğitiminde SPÇ Modelinin Uygulanması

Bu bölümde, R yazılımında matrisler içinde istenilen elemanları seçme sürecinin öğretilmesi SPÇ modeli ışığında incelenmiştir. Öğrencilerin R yazılımındaki vektörler hakkında bilgi sahibi olduğu varsayılarak, SPÇ modeli rehber olarak kullanılmıştır. Modelin R öğretiminde uygulanması pratik örneklerle açıklanmıştır.

Hedef problemi tanımlama aşamasında, problemin bileşenleri kodlanır ve ilişkiler anlaşılmaya çalışılır (Sak, 2011). Süreç kodlamasında, tüm bileşenler kodlanır; seçici kodlamada ise gerekli bilgiler ayırt edilerek kodlanır (Davidson ve Sternberg, 1984). Bu aşamada öğrencilerden problemin bilinen ve bilinmeyen bileşenlerini açıklamaları istenir. Öğretmenler, "Problem nedir?", "Problem hakkında ne biliyoruz?" ve "Problemin bilinmeyenleri nelerdir?" gibi sorular kullanır. Hedef problem, öğrenciler için zorlayıcı ve önceki öğrenimlerini kullanabilecekleri bir problem olmalıdır (Sak, 2011). Şekil 1'deki örnek hedef problemde, öğrencilerden "matrix [7,5]" kodunun ne yaptığını açıklamaları istenmiştir.

Kaynak problemi tanılama aşamasında, öğrencilerden problemler arasında seçici karşılaştırmalar yapmaları istenir. Seçici karşılaştırmada analojiler kullanılır. Hedef problem, öğrenciler analoji yapabilmeleri için ipuçları içermelidir. Bu aşamada öğrencilerden analojik bir problem belirlemeleri veya verilen kaynak problemlerden analoji yapmaları istenir. Öğretmenler, "Bu problemle daha önce karşılaştınız mı?" ve "Başka benzer bir problemle karşılaştınız mı?" gibi sorular kullanır (Sak, 2011). Şekil 2 ve 3'teki kaynak problemler incelendiğinde, öğrencilerden "data [10]" ve "data [1:10]" kodlarının çıktılarının ne olduğunu açıklamaları istenmiştir.

Hedef problemi çözme aşamasında, öğrencilerden hedef problemi doğru analojik transferle çözmeleri beklenir (Sak, 2011). Analojik transferin gücü, kaynak problem ile hedef problem arasındaki analojiye bağlıdır (Holyoak ve Koh, 1987). Bu aşamada öğretmen, "Kaynak problemin çözüm yöntemini hedef problemi çözmek için nasıl kullanabilirsiniz?" sorusunu kullanır. Hedef problem çözüldükten sonra, "Problem çözme adımlarının doğruluğunu nasıl kanıtlayabilirsiniz?" sorusuyla öğrencilerin çözüm sürecini kontrol etmelerini sağlar (Sak, 2011).

Orijinal problem oluşturma aşamasında, öğrencilerden hedef probleme benzer, ancak daha karmaşık bir özgün problem oluşturmaları beklenir. Öğretmen, "Hedef problemden daha ileri ve zor problemler yazabilir misiniz?" sorusunu kullanır. Öğrenciler uygun problemler oluşturamazsa, öğretmen öğrencilere orijinal problemi sunar (Sak, 2011). Şekil 4'te, R yazılımında matrisler içinde istenilen elemanları seçme sürecinin öğretimi için örnek özgün problem gösterilmektedir.

Orijinal problemi çözme aşamasında, öğrencilerden hedef problemde kazandıkları analojik transfer deneyimi ile özgün problemi çözmeleri beklenir. Öğretmen, "Hedef problemin çözüm yöntemini özgün problemi çözmek için nasıl kullanabilirsiniz?" sorusuyla süreci başlatır. Öğrencilerin çözüm sürecini kontrol etmeleri için "Problem çözme adımlarının doğruluğunu nasıl kanıtlayabilirsiniz?" sorusunu kullanır (Sak, 2011).

Değerlendirme aşamasında, öğrencilerden problem çözme sürecinin tüm aşamalarını ve deneyimlerini değerlendirmeleri beklenir. Öğretmen, "Problemleri çözerken ne öğrendiniz?" sorusuyla değerlendirme sürecini başlatır. "Problem çözerken analojileri nasıl kullandınız?",

"Orijinal problemleri oluştururken analojileri nasıl kullandınız?" ve "Problem çözerken nasıl seçici oldunuz?" sorularıyla sürecin değerlendirilmesini sağlar (Sak, 2011).

Sonuç ve Öneriler

SPÇ modeli, matematiksel problem çözme modeli (Polya, 1957), içgörülü düşünme teorisi (Davidson ve Sternberg, 1984) ve yaratıcılık araştırmalarına (Sak, 2011) dayanan yeni bir modeldir. Alan yazında SPÇ modeli genellikle matematik bağlamında değerlendirilmiştir. Bal-Sezerel ve Sak (2013), modelin matematik dışındaki disiplinlere de uyarlanabileceğini belirtmektedir. Kılıç ve Ayas (2017), modelin fen bilimlerine uyarlanmasını ele almıştır. Bu çalışmamız, SPÇ modelinin R yazılımında matrislerdeki elemanların seçilmesi sürecine uyarlanması açısından özgün bir çalışmadır. Önceki çalışmalar, SPÇ modelinin lisans veya lisansüstü derslere ve çeşitli disiplinlere uyarlanması gerekliliğini ortaya çıkarmıştır. Bu çalışma SPÇ modelinin lisansüstü dersler ve diğer disiplinler için de uyarlanabileceğini örneklerle göstermektedir. Gelecek çalışmalarda, SPÇ modeli R öğretimindeki diğer konulara ve farklı disiplinlere uyarlanabilir. Uygulamada, öğretmenler kaynak ve hedef problemler arasında doğru analojik aktarımı sağlamada, SPÇ modelinin altı adımı boyunca öğrenci katılımını sürdürmede ve öğrencilerin R programlama ve matrisler konusundaki ön bilgi düzeylerindeki farklılıkları ele almada zorluklarla karşılaşabilirler. Ayrıca, öğrencilerden bağımsız olarak özgün problemler yaratmaları istendiğinde bilişsel yük artabilir. Bu durum, öğretmenlerin ek rehberlik sağlamasını gerektirebilir. SPÇ modeli, yapılandırılmış problem çözme gerektiren disiplinlerde özellikle etkili olabilir. Bunlar arasında veri bilimi, istatistik, mühendislik ve bilgisayar bilimleri dersleri yer almaktadır. Öğretmenlerin adım adım rehberlik, örnekler ve kademeli zorluklar sunmaları önerilir. Öğrencilerin analojik akıl yürütme becerilerini desteklemek, özgün problemleri aşamalı olarak karmaşık hâle getirmek ve ilerlemeyi yakından izlemek etkili öğrenme sonuçları için önemlidir. Gelecek araştırmalar, SPÇ modelinin R ile ilgili diğer konulara uygulanmasını, deneysel tasarımlar kullanarak etkinliğinin değerlendirilmesini ve farklı öğrenci grupları için optimizasyon yollarının araştırılmasını kapsayabilir. Dijital araçların SPÇ adımlarını destekleyecek şekilde entegrasyonu, bilişsel yükü azaltabilir ve modelin pratik faydasını artırabilir.