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# THE ASSOCIATION OF LEARNING STYLES WITH KNOWLEDGE AND PERFORMANCE IN VERTEBRATE IDENTIFICATION OF BIOLOGY STUDENTS

**Kalender Arıkan**

**Abstract.** *Learning style (LS), either visual or verbal, has become debatable in the field of education vis-à-vis its relation to student success. However, it remains a valuable research theme for improving learning activities in the teaching of highly visual science fields, including biology, physics, and chemistry. Previous studies have primarily focused on the success of participants in the courses they took according to their predetermined learning preferences. Conversely, in this study, all participants attended the vertebrate course and took the same tests. Notably, this study aimed to reveal the relationship between participants' LS, the type of acquired knowledge (visual or verbal), and the retention of knowledge. Accordingly, a self-reported, revised Visualizer-Verbalizer Questionnaire (VVQ) and interviews were used to assess participants' (N = 66; 38 females and 28 males) LS. According to the study results, the visualizers' identification test scores correlate with LS in the first tests, while those of the verbalizers do not. Retention tests are a distinctive factor in revealing the relationship between LS and test scores. This study shows that investigating the effects of LS in different circumstances contributes to the field of education, and that more in-depth data can be obtained from individuals' learning activities.*

**Keywords:** *visual and verbal knowledge, learning outcomes, learning style, biology education*

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## Introduction

### *Learning Style*

Learning styles (LS) have long been discussed and studied in the field of education as an important concept believed to influence individuals' learning. The term learning style describes not only individuals' beliefs, habits, and preferences (Messick, 1976) but also their preferred modalities of learning, such as visual and verbal (Pashler et al., 2008). Felder and Solomon (2023) have defined visual learners as students who remember the visual representation of course materials, while they have described verbal learners as those who retain written words and spoken explanations. The learning process of visual and verbal learners has been explained by Paivio (1978, 1986) based on dual coding theory (DCT). According to DCT, some students tend to learn visually (visualizers), while others tend to learn verbally (verbalizers; Paivio, 2014). However, the different definitions and explanations of visual and verbal LSs do not reconcile the nomenclature (Cassidy, 2004). Studies related to teachers', university instructors', and teacher candidates' opinions on LS have shown not only that they recognize LS as a better way of learning individually but also that it has had a positive effect on students' achievement in the courses (Dekker et al., 2012; Dekker & Kim, 2022; Horvath et al., 2018; Newton & Salvi, 2020; Ruhaak & Cook, 2018). However, much research related to LS in the last decade has concluded that there was limited (Knoll et al., 2016; Pashler et al., 2008) or no evidence (Krätzig & Arbuthnott, 2006; Rogowsky et al., 2015; Touloumakos et al., 2023) to support the idea that matching teaching methods to a learner's preferred LS improved the learning outcomes of individual students (Dantas & Cunha, 2020; Lokare & Jadhav, 2024; Lyle et al., 2023). Furthermore, LS has been pronounced as a neuromyth or misinterpreted concept in previous studies (Dekker et al., 2012; Touloumakos et al., 2023).

The results of one of the latest studies related to LS by Rogowsky et al. (2020), conducted with fifth-grade students, revealed a significant relationship between auditory or visual LS preference and comprehension. The results have shown that fifth graders with a visual LS scored higher than those with an auditory LS on listening and reading comprehension measures (Rogowsky et al., 2020). The researchers have concluded that matching teaching to meet a student's auditory or visual LS had no effect on student achievement (Rogowsky et al., 2020), similar to previous research on different groups of learners (Rogowsky



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et al., 2015). Knoll et al. (2016) have tested the hypothesis that the popularity of an LS is maintained because it is associated with subjective aspects of learning, such as judgments of learning (JOLs). They have reported that LS was not associated with recall performance. In addition, the results have indicated that LS has been associated with subjective, but not objective, aspects of learning (Knoll et al., 2016). They hypothesized that higher visualizer (verbalizer) scores were associated with higher immediate JOLs for pictures (words) (Knoll et al., 2016).

Nguyen et al. (2024) have focused on designing and piloting a model to determine students' LSs to create personalized online courses, in addition to identifying an effective LS method and evaluating its learning outcomes. Nguyen et al. (2024) have achieved an accuracy of up to 0.95 in measuring participants' LS in their study results. They have also demonstrated that learning outcomes improve when learners engage with materials and activities tailored to their LSs, contrasting with findings from other studies. Additionally, students with a visual LS have had better learning outcomes (Nguyen et al., 2024). Koć-Januchta et al. (2017) have also conducted a study employing eye tracking as an innovative approach to research learning differences between visualizers and verbalizers. One of their main hypotheses has suggested that visualizers tend to focus on images longer than verbalizers, while verbalizers typically spend more time focusing on texts than visualizers. Participants' eye-tracking and questionnaire results confirmed the researchers' major hypotheses. In summary, the researchers have concluded that individuals, categorized by their visualizer-verbalizer cognitive style, show differences in learning behavior regarding their use of pictorial and verbal information during learning (Felder & Silverman, 1988).

### *Learning Style in Biology Teaching*

Visuality and visual skills are particularly important in major scientific fields, such as engineering, chemistry, and biology (McGrath & Brown, 2005; Uttal & Doherty, 2008). Additionally, engineers and scientists are generally visual thinkers, with creativity in science closely linked to visual skills (Mathewson, 2005). Likewise, biology is a highly visual science (LaDue et al., 2015) because of its complicated processes, such as mitosis and meiosis phases, internal anatomies, or the transcription and translation of DNA (Jones & Broadwell, 2008; Novick & Catley, 2016; Schönborn & Anderson, 2009). Subsequently, the awareness of the educational value of visual objects in science education has significantly increased in recent years (Cook, 2006; Gilbert, 2005).

Various studies have demonstrated that visualizations in biology learning improve the understanding of complicated processes and reduce the learning time and text required (Finnan et al., 2005; Lee & Tsai, 2013; McGrath & Brown, 2005). However, visuality cannot provide comprehensive learning materials without text, which is a part of effective learning and plays an integral role in teaching biology (Jian, 2016; Kloser, 2013). In science education, a combination of visual and verbal information is widely used to display educational material (Cook, 2006). However, some biology teaching methods, such as laboratory courses, still need to be more visual owing to their experimental and practical structures (LaDue et al., 2015). Laboratory courses, as a part of biology teaching, provide insights into the nature of scientific methods (Hodson, 1990) for students learning in cognitive and affective domains (Lee et al., 2012; Von Secker & Lissitz, 1999). Studies have demonstrated that laboratory courses can have a positive impact on students' achievements in science (Von Secker & Lissitz 1999), and visualizations in laboratory courses reduce the information load on working memories and provide more experiences related to the theme or method (Dechsri et al., 1997; Muhamad et al., 2012).

Lyle et al. (2023) have conducted one of the latest studies regarding LS in biology lessons. They examined an LS dimension with perceptual modality, an active-reflective LS dimension, and an interest in authentic learning materials (a digital biology textbook chapter) as a part of the matching hypothesis (Lyle et al., 2023). According to the matching hypothesis, as a part of LS, matching teaching methods to a learner's preferred LS improves learning outcomes (Felder & Silverman, 1988). Their results have shown no interaction between teaching methods and active-reflective LS preferences. They have concluded that learning was best when the teaching method mismatched the preferred LS, relative to when the teaching matched the preferred LS (Lyle et al., 2023).

It has been concluded from several studies that LSs improve learning outcomes in some cases, whereas they do not have any effect in others. The results should not be interpreted as indicating that LSs are a neuromyth or invalid, but that they do not improve student learning in all circumstances.

### *The Aim of this Study*

The effectiveness of LS on learning outcomes varies from positive to neutral, as shown in many studies. Moreover, LSs have been considered as a neuromyth in recent studies. However, researchers have tested the learning outcomes of


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students by designing studies in which participants are divided into suitable groups according to their predetermined LS and compared academic achievement in a significant part of the research. Previous studies have mostly focused on determining what type of LS (visual or verbal) is preferred by students before a learning activity and its effect on learning outcomes. Researchers have discussed LS from different perspectives and put forward theories such as DCT (Paivio, 1978, 1986), cognitive theory of multimedia (Mayer, 2005), and integrated model of text, and picture comprehension (Schnotz, 2005), which are based on the effect and perception of different combinations of visual and written components on the individual. The multitude of studies and theories on the subject further indicates the complexity of the research field. According to Schnotz et al. (2012), the quality of learning inside and outside schools depends largely on knowledge acquisition from text and pictures, and verbal and pictorial knowledge is acquired in working memory through visual and auditory channels.

In previous studies, students participate in courses designed according to their predetermined learning preferences as visual or verbal, and their performance is evaluated within this framework. However, in these studies, no research or evaluation has been conducted on which type of knowledge acquisition students will use first when they need to apply knowledge acquired both verbally and visually. This has required a more controlled investigation into how learning experiences, rather than grouping based on predetermined learning styles (LS), influence the type of knowledge students use in assessments. Thus, a study focusing not on how knowledge is acquired but on how the acquired knowledge is used can contribute to addressing the gap in the literature. In this context, this study aims to reveal which of the visual and verbal knowledge more frequently rely on when identifying visual specimens, as well as the relationship between the type of acquired knowledge used and their learning preferences, its association with learning performance and retention of knowledge. Consequently, answers to the following research questions were sought within the aim of the study:

Does student performance differ based on the type of acquired knowledge (visual or verbal) used?
Is the type of acquired knowledge (Visual and verbal) associated with learning preferences by self-report, VVQ, and interview in terms of pre-, post- and re-test?
Is there any correlation between learning preferences by self-reported (Interview) and T-VVQ?

Accordingly, three different approaches were used to assess students' LSs (visual or verbal). These are self-reports by students, data from the revised Visualizer-Verbalizer Questionnaire (VVQ) (Kirby et al., 1988), and the type of knowledge acquisition that students call when identifying the species determined through interviews.

## Research Methodology

### *Design*

The single-group longitudinal research method, which included pre-, post- and re-tests, was determined as the research design, since all participants participated in the same activities and measurements, which were taken from the same group at different times. In this context, participants were randomly selected from among volunteers. The research was conducted between the end of February and the beginning of June 2024 at Hacettepe University in Ankara. This study entails four stages. In the first part, participants indicated their LS (verbal and visual) as a self-report, and the T-VVQ was applied to all participants to identify their LS one week prior to the laboratory session. In the second part, all participants were taught how to identify snake species using a dichotomous identification key. Each of them identified 15 snake species in the laboratory using the key, first with the help of the teacher and then independently. The identification process continued until all students correctly identified the species and lasted between 3 and 4 hours. One day later, they took a written test to identify species to assess their verbal knowledge as the third part. Afterward, they identified snake species without using a species identification key to imitate the visual examination for assessing visual knowledge. An interview was conducted with students to detail the steps they followed to identify the type during the visual examination after the exams. They took the same exams for the written test and visual examination three weeks later as the post-test and two months later as the re-test, following the end of the second part.

### *Participants*

The research was conducted in Ankara - Türkiye, where 3 out of 21 universities have only biology, and 2 universities have both biology and biology teaching departments. Approximately 554 second and third-year students are enrolled in these departments, constituting the research population. The required sample size for a population of 554 individu-


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als was determined using statistical power analysis, a method widely recognized for ensuring adequate sample sizes in research (Cohen, 1988; Faul et al., 2009). The calculations assumed a 95% confidence level ($\alpha = .05$), 80% statistical power ($1-\beta = .80$), and a medium effect size ($d = .5$) based on Cohen's benchmarks for effect sizes (Cohen, 1988). According to the power analysis, the minimum sample size required to achieve statistically significant results was found to be 57 individuals. The sample size calculation also incorporated finite population correction to account for the limited population size, ensuring a more precise estimation (Krejcie & Morgan, 1970; Abraham & Russell, 2008). 66 of these students (11.91% of the total) were selected from among volunteers to form the research sample. Participants were 66 (38 female and 28 male) undergraduate second- and third-year biology and biology teaching students aged between 18 and 28 years ($M = 20.18$; $SE = .22$) enrolled in a vertebrate biology course at Hacettepe University. Informed consent was obtained from the students after a full explanation of the experiment that involved recording their emotional and academic states.

### *Identification of Learning Preferences*

The revised VVQ (Kirby et al., 1988) was translated into Turkish to evaluate participants' preferences for learning verbal (i.e., verbalizers) and visual (i.e., visualizers) information. Comprising 20 statements, the VVQ includes equal numbers of items for verbal and visual learning preferences. Additionally, it contains 10 extra items related to dream vividness, which were not utilized in this study.

The VVQ was translated from English to Turkish (T-VVQ), and a final questionnaire was administered to 168 (92 female and 72 male) university students at the beginning of the 2023-2024 spring semester to determine its validity and reliability. The T-VVQ has two subscales, each with ten statements whose responses are evaluated on a 5-point Likert scale ranging from totally agree to totally disagree. The VVQ reliability coefficient (α) was reported by Kirby et al. (1988) as .70 for the verbal and .59 for the visual dimensions. The reliability values of each subscale of the T-VVQ in recognizing the cognitive styles of visualizers and verbalizers are .73 and .72, respectively (Cronbach's alpha). The reliability coefficient values for both sub-dimensions were satisfactory and acceptable according to the Nunnally criteria (1965). The dataset's suitability for factor analysis was assessed using the Kaiser-Meyer-Olkin coefficient (Kaiser, 1974) and Bartlett's (1950) sphericity test, which indicated appropriateness with a value of .76. Confirmatory factor analysis conducted via the LISREL software validated the factor analysis results. Following this, the T-VVQ items were re-clustered according to each dimension.

### *Snakes and Dichotomous Key*

Participants use a dichotomous key to identify snake species in Türkiye. A dichotomous key is a powerful tool for classifying and identifying both objects and living organisms (Watson & Miller, 2009). This tool offers a straightforward approach for users to choose between two paired statements that describe different morphological characteristics. With each selection, the key directs the user to the next set of statements, continuing this process until the object or organism is identified (Di Nicola et al., 2022; Sinh et al., 2017). Dichotomous keys are widely used by researchers, technicians, and students, and they can also be valuable for individuals outside the scientific community (Di Nicola, 2019).

Participants identify 15 snake species using the identification key. However, two snake species, grass snake (*Natrix natrix*) and dice snake (*Natrix tessellate*), had been chosen as the target species. These two species were chosen because they were distinguishable from each other based on a few morphological features. Participants need to identify the species carefully to distinguish them. A 50-item dichotomous key was used to identify snake species. However, among these items, only the following eight are used to identify the two species. In addition, the eight items are also a verbal definition of the species.

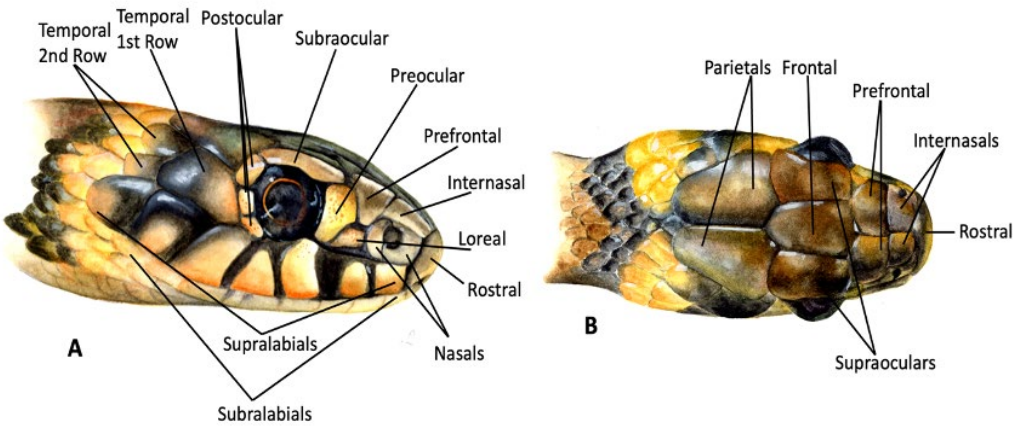
1. Ventral plates reach the lateral edges of the ventral side and subracaudalia are in two rows.
2. The upper part of the head is covered with plates, and the frontale plate is in contact with the supraocularia plates. The anal plate is double. The pupil is round (Different at Telescopus sp.). Family: Colubridae
3. The frenale plate is separated from the anterior edge of the eye by praeocularia plates. Very rarely, the frenale plate may be absent.
4. Supralabialia is in contact with the lower edge of the eye. There is a pair of praefrontalia between the frontale and internasalia plates.
5. Dorsal scales are in 19 rows (Very rarely, there may be 17 or 21)


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6. Postocularia abut on posteriorly only by a large temporal plate. The dorsal scales are clearly keeled. *Natrix sp*.
7. There is one praeocularia in front of the eye. There are seven supralabialia, and demilune yellow, rarely reddish spots are usually present on the back sides of the head. Tail scales are flat or slightly keeled. *Natrix natrix*
8. There are two to four praeocularia in front of the eye. There are eight supralabialia, and demilune yellow, rarely reddish spots on the back sides of the head are usually absent. The tail is keeled. *Natrix tesselata*

**Figue 1**
*Nomenclature of Main Head Scales of a Colubridae Snake (Natrix natrix); Lateral (A) and Dorsal (B) View*




*Writing and Identification Tests*

The definition question (DQ) for measuring verbal knowledge was administered one day after the end of the identification course. The DQ related to the basic verbal descriptions of both animals was completed. A 5-point scoring rubric was developed to categorize responses from entirely incorrect to entirely correct, assigning specific points for partially and fully accurate answers. In a practical test (PT), participants identified specimens to gather systematic data for assessing visual knowledge. When the DQ was asked in the same examination, the PT was asked in a different exam to prevent the comparison of the two specimens as an indicator. Responses to the PT were evaluated as either correct (1 point) or incorrect (0 points). Both assessments were scored by two instructors who were unaware of which lesson the participants had completed. The mean scores of the two lecturers were used to calculate the DQ score, as the correlation between the scores of the two lecturers on the DQs was acceptable ($r(80) = .97$, $p < .001$).

*Interviews*

The interviews were related to the identification test answers and conducted after the tests in a face-to-face meeting (Brenner, 2006). The main purpose of the interviews was to explore the students' identification strategies and obtain more details related to the knowledge source (visual or verbal) benefitted from. Five questions were created for the interviews to determine the students' self-reported learning preferences (Visual or verbal), the type of exam they preferred, and their use of the identification key during the exam, with each aspect addressed by a separate question. The questions also aim to reveal whether the students refer to the dichotomous key or snake images that they remember during the identification. The terms, such as item, dichotomous key, and identification key, mentioned by participants in their answers were evaluated as verbal, and expressions, such as snake image, were evaluated as visualizers.

1. Which type of examination do you prefer to take? (Why)
2. From where (or how) did you start to identify the species?
3. What did you think in relation to the identification steps when you first saw the snake?
4. Did you follow the items based on the dichotomous key for identification?
5. How do you define your whole identification process: visual or verbal?


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### *Data Analysis*

The Wilcoxon signed-rank test assessed score changes within each group over time, while an independent samples t-test analyzed differences between groups and genders. Spearman's rank correlation coefficient was calculated to explore correlations between group attitudes and knowledge. To compare continuous outcomes between two independent samples, the Mann-Whitney *U* test was utilized. Confirmatory factor analysis for the preliminary T-VVQ test data was conducted using the LISREL program. Additionally, numerical data from tests, interviews and scales were statistically analyzed using IBM SPSS Statistics 23.0.

## Research Results

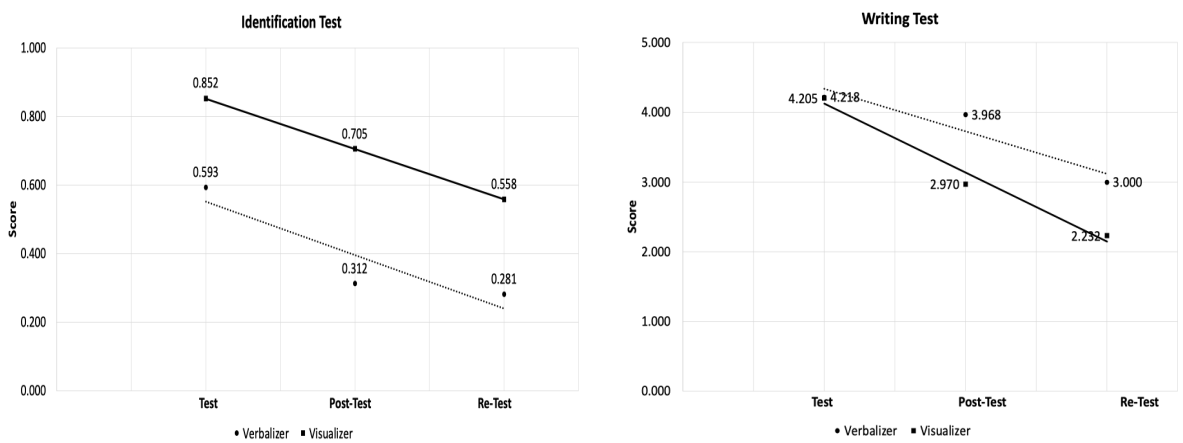
### *Learning Preferences*

More than half of the participants reported their learning preference as visual ($N = 40$; female: 22, male: 18), and the remaining as verbal ($N = 26$; female: 16, male: 10). There was no statistically significant difference in self-reported LS according to gender ($U = 486.00$, $Z = - .512$, $p = .602$) and age ($U = 414.00$, $Z = - 1.423$, $p = .155$). The numbers of visualizers ($N = 34$; female: 18, male: 16) and verbalizers ($N = 32$; female: 20, male: 12) based on the T-VVQ were similar. Correlatively, no statistical difference was found between participants' learning preferences by T-VVQ in terms of gender ($U = 492.00$, $Z = -.779$, $p = .436$) and age ($U = 444.50$, $Z = - 1.305$, $p = .192$). There was a negative correlation ($r_s(64) = -.658$, $p < .01$) between self-reported and T-VVQ learning preferences.

### *Tests*

Gender is not a determinative factor on the writing ($U = 392.00$, $Z = - 1.951$, $p = .051$) and identification ($U = 520.00$, $Z = - 0.202$, $p = .840$) test scores of participants. The graphs in Figure 2 show the mean temporal changes in the writing and definition tests (test, post-test, and retest). The visualizers ( = .852) by T-VVQ clearly have higher scores than the verbalizers in the identification tests ( = .593). Accordingly, although there are statistical differences between visualizers and verbalizers by self-report ($U = 352.00$, $Z = - 2.858$, $p = .004$) and also T-VVQ ($U = 403.00$, $Z = - 2.345$, $p = .019$) on the identification test results, no statistical differences are found between writing test scores by learning preferences ($p > .05$). The identification test mean scores of students with both LSs based on the VVQ decreased linearly from the first test to the retest over time (Figure 2). Nevertheless, visualizers were more successful than verbalizers in all identification tests. There were no statistically significant differences in the first and post-identification test scores ($p = .197$) of the visualizers, while there were statistically significant differences between the re-test, first-, and post-tests ($p < .05$). Similarly, the first and post-writing test scores of verbalizers differed from those of the re-test. However, statistically significant differences were found between all the identification test scores for verbalizers and all the writing test scores for visualizers ($p < .05$).

**Figure23**
*Temporal Changes in Identification and Writing Test Scores According to Learning Preferences by T-VVQ*



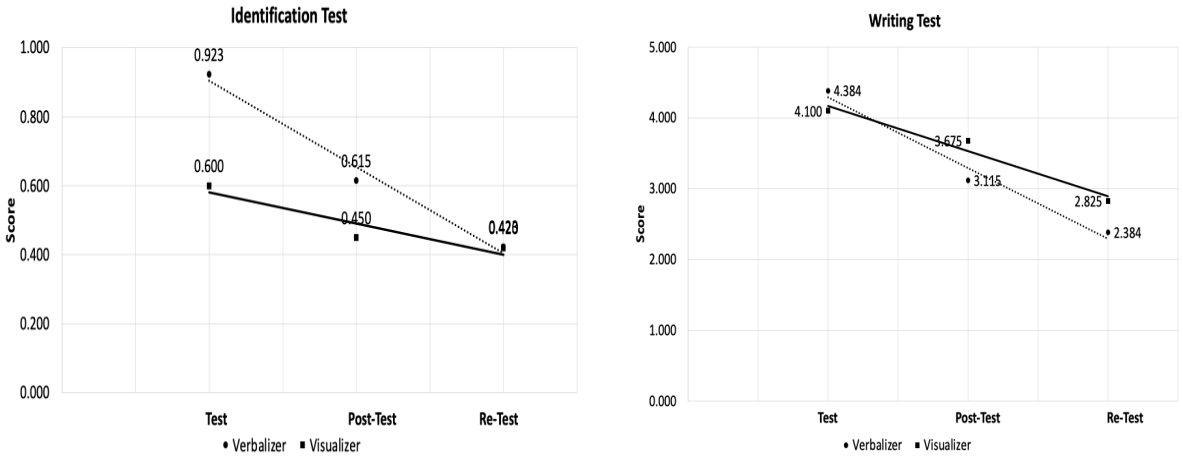


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The test scores of participants based on self-reported learning preferences are complicated in comparison to the T-VVQ. The mean score of the first identification test of the verbalizers ( = .923) is higher than that of the visualizers ( = .600), and also, there are statistically significant differences between them ($U$ = 352.00, $Z$ = -2.858, $p$ = .004), as shown in Figure 3. There were no statistically significant differences between the other scores of the identification tests, despite the higher scores of the verbalizers. Nevertheless, the mean re-test score for both groups was .42. Interestingly, while the writing test scores of both preferences were very close to each other, without statistically significant differences ($U$ = 419.00, $Z$ = -1.424, $p$ = .155), visualizers had higher scores than verbalizers at post- and re-tests, with statistically significant differences ($p$ > .05).

**Figure 3**
*Temporal Changes in Identification and Writing Test Scores According to Learning Preferences by Self-Report*




*Interviews*

The first question of the interviews is related to participants' test preferences between writing and identification. This is also similar to participants' self-reported questions in terms of expected answers. The choice of test implies decelerating learning preferences simultaneously. However, there is no statistical relationship between the answers to the first question and the students' self-reported learning preferences ($rs$(64) = -.40, $p$ = .749) and their learning preferences as determined by the T-VVQ T-VVQ ($rs$(64) = -.006, $p$ =.964) as visual or verbal. After participant response, they are asked a "*why*" question to obtain a deeper understanding of the insight. For example, if the response is *a writing exam, the question is, Why did you prefer the writing/identification test*? The responses were grouped according to their meanings as feelings, interests, and others (ungrouped). Participants ($N$ = 24) who preferred a test because of their feelings expressed the sentences *I feel comfortable/more successful/positive/brave/*. Participants ($N$ = 29) who preferred a test because of their interest expressed self-words that were *attention/absorbed/curious/interest.*

Notably, there was a positive and statistically significant correlation between the interest group and T-VVQ visualizers ($rs$(22) = .755, $p$ = .031). Verbalizer expression was not statistically related to any parameter ($p$ > .05). The second question, *From where (or How) did you start to identify the species?* was also aimed at identifying student learning preferences. There were two expected answers, namely, identification key or snake, to group participants. All participants used these words in their answers. Participants who used or thought about the first dichotomous key were identified as verbalizers ($N$ = 28), and those who looked at or took the snake first were identified as visualizers ($N$ = 38). The learning preferences for the second question were not statistically correlated with those for the first question and were self-reported. Nevertheless, there was a slight positive correlation between the second question and visualizers ($rs$(36) = .510, $p$ = .041) and verbalizers ($rs$(26) = .593, $p$ = .047) in the T-VVQ. The third question, *What did you think in relation to identification steps at first when you saw the snake?* aimed to determine participants' thinking strategies for solving problems in relation to LS. However, the answers were unexpectedly in large scale *worry* ($N$ = 4), *fear of snakes* ($N$ = 7), *whole courses* ($N$ = 8), *solving strategy* ($N$ = 8), *dichotomous key/item of key* ($N$ = 18), and *snake/other snake which identified/snake image* (N = 21). Verbalizers ($N$ = 12/18) were predominant among those who provided a *dichotomous key* as their answer, and visualizers ($N$ = 15/21) were more in number among those who gave *snake/*


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*other snake which identified/snake image* answer. Similar to the second question, the LS thereof was not statistically correlated with the first question and self-report, while there was a positive correlation between the *snake/other snake which identified/snake image* answer and visualizers ($rs(13) = .673$, $p = .033$), as well as between *dichotomous key/item of key* answer and verbalizers ($rs(10) = .505$, $p = .042$) by T-VVQ. The next question, *Did you follow the items of the dichotomous key for identification, respectively?* was a short-answer question. Thirteen participants expressed that they checked all items in the correct order. All of them were verbalizers according to the T-VVQ and successfully completed the identification test. Only 19 participants were successful in the first identification test from verbalizers by T-VVQ. The others who expressed mostly ($N = 16$), partly ($N = 22$), or never ($N = 12$) checked the items were mixed groups of both preferences. The last question in the interview was related to the participants' definition of the identification process as verbal or visual. The answers did not correlate with the self-reported or T-VVQ learning preferences. However, participants who were identified as visualizers ($N = 38$) and verbalizers ($N = 28$) based on the results of the second question gave the same answer to the second question as visual ($N = 38$) or verbal ($N = 28$). As expected, the 13 participants involved in responding to the fourth question, gave the answer verbally, and 12 of them were the same participants of the third question.

## Discussion

The study mainly focuses on what type of acquired knowledge (visual and verbal) is preferred by students during tests, especially identification tests. However, it was necessary to first identify the type of LS of participants to achieve the main research aim. It is clear from the results that there is a relationship between LS (T-VVQ) and test scores, as shown in many studies (Dekker & Kim, 2022; Dekker et al., 2012; Horvath et al., 2018; Newton & Salvi, 2020; Ruhaak & Cook, 2018), while these results do not match up with tests in all circumstances. Even Rogowsky et al. (2020) and Touloumakos et al. (2023), who considered LS as a neuromyth, stated in their own research that visualists were more successful than others. Taken together, these results show that LS finds a form of expression in participants' brains. It is also clear that the first identification test scores of participants are statistically correlated with the visual LS using the T-VVQ in this study. Verbalizers had scores similar to those of visualizers in the first writing test. Most researchers (Falkenhainer et al., 1989; Gentner, 1989; Miles & Minda, 2011; Schnotz, 1993) have explained the differences between the visual and verbal systems as a result of poor performance with the verbal system and interference with executive resources. However, retention has emerged as a more important factor in clarifying the association between LS (T-VVQ) and success (Tranel et al., 2005; Welcome et al., 2011). A statistically significant difference was found between LS by the T-VVQ and success according to all post-tests and re-tests. Thereafter, verbalizers in the writing tests and visualizers in the identification tests maintained their superiority in terms of scores throughout the tests. Tranel et al. (2005) and Welcome et al., (2011) stated that verbalizers had greater retention of words that incorporated both cerebral hemispheres to a greater degree. This can also be interpreted as participants being more inclined to use one of the types of acquired knowledge, and this tendency is related to their LS. Additionally, Dunlosky et al. (2013) interpreted that participants benefited from a limited number of materials and short retention intervals. However, Rogowsky et al. (2020) found no relationship between LS, teaching method, and performance for either immediate comprehension or two-week retention. The statistical results between the test scores and self-reported LS were not meaningful compared to the T-VVQ. For example, the higher score of verbalizers in the identification test was because many verbalizers incorrectly defined themselves as visualizers, and therefore, the mean scores of visualizers decreased. Similarly, as the verbalizers defined themselves as visualizers, the scores of the latter were higher than those of the verbalizers in the writing test, and a statistical difference was found between the scores. These results show that the self-report method for determining participants' LSs is neither successful nor distinctive, as shown in other studies (Kirschner, 2017; Oliveira et al., 2023; Touloumakos et al., 2023).

The interview constitutes a vital part of the study in terms of the in-depth evaluation of LS and test results. While the first question of the interview had an almost similar meaning in terms of outcomes to the questions that asked for the self-reported LS, there was no statistical correlation between them. This indicated that the participants did not directly correlate the type of test with the type of LS in their minds. The "*why*" question asked afterward revealed different emotional dimensions regarding students' test preferences. Here, two sub-dimensions were identified from the expressions as feelings and interests. A statistically strong correlation was found between the interest dimension and the visual LS using the T-VVQ. Many other similar studies (Berlyne, 1958; Durik & Harackiewicz, 2007; Harackiewicz et al., 2016; Silvia, 2005) show that visual stimuli increase interest, arousal, and attention in individuals. This shows that LSs not only entail success but also trigger students' feelings and interests (Dunlosky et al., 2013). The third question revealed which of the acquired knowledge was first used by participants, in line with their visual and verbal LS based on


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the T-VVQ. It can be understood that participants tend to first use the acquired knowledge that they trust the most. This is because most verbalizers use verbal knowledge (*dichotomous key/Item of key*), and visualizers use visual knowledge (*snake/other snake which identified/snake image*) during identification. The separation of the use of the first knowledge source into visual and verbal sources at the beginning of the tests might be related to the work of van Dijk and Kintsch (1983), who explained that knowledge processing in working memory occurs in two different representational channels: verbal and visual. Confirming both the results of the third question and van Dijk and Kintsch's (1983) explanation, all 13 students who followed the items in the *dichotomous key* in the fourth question were verbalizers, and 12 of them gave the *dichotomous key* answer for the third question. While it is expected that the answer to the fifth question matches the self-reported LS, it matches the answer to the second question of the interview. This can be interpreted as the interviews being internally consistent. Similarly, the data obtained from the interviews, T-VVQ, and test scores of visualizers and verbalizers via the T-VVQ are generally compatible relative to the self-report.

## Conclusions and Implications

Labeling LSs as a neuromyth is not a completely correct approach. However, as shown in this study, indicating that the perception that a student is successful in every circumstance due to LS is not entirely effective in learning activities. Nevertheless, the differences between the success of visualizers and verbalizers by retention tests, as well as the fact that visualizers have different emotions of interest, show that individuals have a background in LSs. This study shows that LSs in different circumstances will contribute to the field of education, and that more in-depth data can be obtained from individuals' learning activities instead of dismissing studies on learning preferences outright. Additionally, this study suggests that, while not applicable to all fields, incorporating learning preferences in teaching methods can be particularly beneficial in highly visual disciplines like biology.

### *Limitations*

The first limitation of this study was that the number of male participants was fewer than that of female participants, although there was no statistical difference between them in terms of the results. The design of the study is a very specific component of a learning activity, even if it is only a biology course. Participants took a dozen courses that had a specific content in connection to snake identification. Naturally, this limits the results of the study.

### *Future Studies*

This study demonstrates that LS remains an important approach for learning activities, and participants tend to first use the acquired knowledge they trust the most. In addition, LS may be related to feelings and interests. In this context, future research should investigate students' decision-making as a flowchart of their challenges with these knowledge sources as visual or verbal. Thus, the connection between visual and verbal knowledge can be enhanced to improve learning outcomes. In addition, the connection and relations between LS and participants' emotions (interests and feelings) should be investigated in detail in future studies.

## Ethical Approval

Ethical approval was obtained from the Social Sciences and Humanities Research Ethics Board, Hacettepe University. The approval number of the study is E-66777842-300-00003284691.

## Declaration of Interest

The author declare no competing interest.

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