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Systematic Assessment of Student Autonomy in Science Process Skills: 9th Grade Physics Curriculum and Textbook Analysis

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Abstract

This study aimed to determine how well a physics textbook aligns with the curriculum -the first skill-oriented one in Türkiye- regarding science process skills and student autonomy. A content analysis of both the curriculum and the textbook was conducted using the Science Process Skills Inventory. Findings revealed that the 9th grade physics curriculum emphasized skills such as "collecting and interpreting data", "communicating", "measuring", and "experimenting" while it neglected "observing", "predicting", and "inferring". The curriculum aimed to develop these skills by encouraging students to plan and take responsibility for their learning activities. The content analysis showed that the physics textbook primarily focused on "collecting and interpreting data", and "measuring" with frequent emphasis on "observing", "classifying", "inferring", and "modeling". However, it largely ignored "hypothesizing", and "defining and controlling variables". The skills were presented in highly structured activities, limiting student autonomy. The results indicated an alignment between the curriculum and the textbook in the inclusion of "collecting and interpreting data", "measuring", and "communicating". However, there was a notable inconsistency in the level of openness. While the curriculum expected students to engage in designing scientific activities, the textbook provided step-by-step procedures that restricted student autonomy to create their scientific processes.

Keywords
1. science process skills
2. student autonomy
3. physics education
4. content analysis
5. textbook analysis

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INTRODUCTION

In recent years, global education systems have focused on enhancing science education by emphasizing both scientific knowledge and the skills used by scientists. Initiatives like the National Science Education Standards in the US (Mangrubang, 2004) and programs in England (Department for Education, 2013), Australia (Bradley, 2005), Jamaica (Beaumont-Walters & Soyibo, 2001), and Türkiye (MEB, 2005) have stressed the importance of teaching scientific processes alongside facts. This approach aims to develop critical thinking and problem-solving abilities among students, preparing them to tackle real-world challenges like climate change and biotechnology (Boujaoude, 2010; Sadler, Chamebers & Zeidler, 2004). Scientific literacy involves not just understanding science but also applying it effectively to personal and societal issues (Lederman & Niess, 1998). Efforts in Türkiye have specifically aimed to integrate Science Process Skills (SPSs) into the curriculum, ensuring that students learn to think like scientists. These skills include observation, hypothesis formulation, experimentation, and problem-solving. By incorporating them into education, the goal is to produce scientifically literate individuals capable of addressing complex issues in society. The physics curriculum, introduced in 2007, incorporated skill objectives in addition to content objectives, prompting textbooks to adapt by including new sections such as activities, problem-solving exercises, and projects (MEB, 2007, 2011). While textbooks play a key role in achieving the curriculum goals (Vera, 2018), an excessive dependence on them may detract from the broader vision of the curriculum (Park, 2005). To determine whether the 9th grade physics textbook aligns with SPSs, it is essential to evaluate how well it mirrors the curriculum's objectives.

SPSs in Science Curricula

Curriculum development now stresses scientific literacy, prompting researchers to analyze its various aspects. Boujaoude (2002) explored the balance of scientific literacy in Lebanon's science curriculum, finding a strong focus on scientific knowledge and the interaction of science with technology and society. However, it lacked emphasis on science as a way of knowing. Similarly, Cansız and Turker (2011) noted a similar approach in the Turkish curriculum, with an overemphasis on the investigative nature of science to the neglect of science as a way of knowing. Bağcı-Kılıç, Haymana, and Bozyılmaz (2008) also identified this oversight in the Turkish science curriculum published in 2005, particularly the neglect of science as a way of knowing in favor of emphasizing the investigative aspect. This facet, essential for comprehending the methodologies and procedures of scientific inquiry, closely corresponds with SPSs and emphasizes the significance of hands-on, mind-on science education.

The Turkish Science and Technology Curriculum (MEB, 2005) prioritizes SPSs, divided into three categories: “planning and starting”, “practicing”, and “analyzing and inferring”. While it emphasizes the investigative aspect of science (Bağcı-Kılıç et al., 2008), the active role of learners in constructing their understanding is lacking (Arsal, 2012). Subsequent revisions in 2013 and 2018 maintained this focus on SPSs but integrated them differently with content objectives. Studies reveal a predominant emphasis on Basic Science Process Skills (BSPSs) over Integrated Science Process Skills (ISPSs) across all curriculum versions and grade levels (Bağcı-Kılıç et al., 2008; Duruk, Akgün, Doğan & Gülsuyu, 2017; Yapıcıoğlu, 2021). Skills like observing, classifying, and communicating are consistently represented, but critical skills like measuring and predicting are often overlooked. Hypothesizing is absent, while defining and controlling variables receive insufficient attention. Experimentation is consistently emphasized, but interpreting data and defining variables are neglected (Bağcı-Kılıç et al., 2008; Duruk et al., 2017; Yapıcıoğlu, 2021). There's a need for a more balanced representation of skills and deeper integration of ISPSs in the Turkish science curriculum.

Research on physics curricula across different countries highlights common trends. In Italy, there's a strong emphasis on the investigative nature of science, focusing on scientific practices like observation and modeling (Caramaschi, Cullinane, Levrini & Erduran, 2021). Similarly, Norway's physics curricula prioritize scientific practices, promoting inquiry-based learning (Kostøl, Bøe1 & Skår, 2023). Turkish studies (Erdoğan & Köseoğlu, 2012; Yılmaz, Öner-Sünkür & İlhan, 2012) indicate an overarching aim of curricula to foster scientific process skills across different grades and disciplines. Comparative analyses show differences in the integration of SPSs, with Türkiye placing greater emphasis on them compared to Hong Kong (Cerit-Berber, 2015). However, there's a limited number of studies examining physics curricula, especially regarding SPSs, both within Türkiye and globally.

SPSs in Science Textbooks

Inquiry-based tasks in science textbooks aim to promote SPSs (Yang & Liu, 2016), but there's a growing concern about the balance between BSPSs and ISPSs. Studies show that many textbooks prioritize BSPSs, like observing and recording data. This trend is observed in textbooks from Bangladesh (Chakraborty & Kidman, 2021), Jordan (Alayasrah & Yahyaa, 2017), Greece (Sideri & Skoumios, 2021), Lebanon (Zeitoun & Hajo, 2015), Ethiopia (Hunegnaw & Melesse, 2023), Indonesia (Halawa, Hsu & Zhang, 2023), Singapore (Halawa, Hsu, & Zhang, 2024), the U.S. (German, Haskins & Auls, 1996; Tamir & Lunetta, 1978), China (Yang, Liu, & Liu, 2019), and Türkiye (Aslan, 2015; Özalp, 2023; Şen & Nakiboğlu, 2014; Yalçınkaya-Önder et al., 2022). While inquiry-based tasks are more common, essential skills like formulating scientific questions (Abraham & Millar, 2008) are often overlooked (Aldahmash, Mansour, Alshamrani, & Almohi, 2016; Chiappetta & Fillman, 2007), limiting students' opportunities for independent investigations. In Turkish textbooks, BSPSs take precedence, with activities mainly focusing on observing, classifying, predicting, and measuring. Despite efforts to incorporate inquiry-based tasks globally, BSPSs still dominate over ISPSs (Aslan, 2015; Özalp, 2023; Şen & Nakiboğlu, 2014; Yalçınkaya-Önder et al., 2022).

Science textbooks aim to foster student autonomy in scientific inquiry, but merely following predetermined steps can hinder higher-order thinking skills (Domin, 1999; Li et al., 2018). Gumilar and Ismail (2023) suggest that textbooks should progressively guide students through scientific experiments. However, Yıldız-Fevzioğlu and Tatar (2012) found that Turkish elementary science textbooks are overly structured, limiting student engagement and critical thinking. Similarly, Turkish physics textbooks focus more on predetermined steps than on independent experimental design (Şen & Nakiboğlu, 2014). Studies show that most textbooks provide explicit instructions, leaving little room for student autonomy (Aldahmash et al., 2016). International examples also show similar trends. Finnish and US high school physics textbooks provide problems and procedures but leave solutions open (Park & Lavonen, 2013), while Indonesian and Singaporean textbooks are structured with set inquiry questions and procedures (Halawa et al., 2023, 2024). Chinese textbooks offer minimal freedom for students to design experiments (Li et al., 2018).

Overall, textbook analyses reveal an imbalance between BSPSs and ISPSs. Although skill-based tasks are included, priority is given to BSPSs, for example observation and data recording, over ISPSs, such as creating questions and independently designing experiments (Alayasrah & Yahyaa, 2017; Aslan, 2015; Chakraborty & Kidman, 2021; Özalp, 2023; Sideri & Skoumios, 2021; Şen & Nakiboğlu, 2014; Yalçınkaya-Önder et al., 2022; Zeitoun & Hajo, 2015). This imbalance limits students' critical thinking and inquiry skills, hindering their autonomy in the scientific process despite efforts to improve SPSs in science and physics textbooks.

Rationale for the Study

Specific attention has been given to SPSs related to one of the NOS aspects, "investigative nature of science", in studies conducted by Alayasrah and Yahyaa (2017), Aslan (2015), Chakraborty and Kidman (2021), Hunegnaw and Melesse (2023), Özalp (2023), Sideri and Skoumios (2012), Şen and Nakiboğlu (2014), Yalçınkaya-Önder et al. (2022), and Zeitoun and Hajo (2015). However, they often overlook student autonomy, despite its crucial role in the relationship between SPSs and inquiry. Therefore, further research is needed to comprehensively assess student autonomy in SPSs-related activities.

Moreover, although research has examined science curricula (e.g., Bağcı-Kılıç et al., 2008; Duruk et al., 2017; Yapıcıoğlu, 2021) and textbooks (e.g., Alayasrah & Yahyaa, 2017; Aslan, 2015; Chakraborty & Kidman, 2021; Özalp, 2023; Sideri & Skoumios, 2021; Yalçınkaya-Önder et al., 2022; Yıldız-Fevzioğlu & Tatar, 2012; Zeitoun & Hajo, 2015) with regard to SPSs, there has been little analysis of these components in physics curricula (e.g., Cerit-Berber, 2015) and physics textbooks (e.g., Şen & Nakiboğlu, 2014). There is limited examination addressing the alignment between the physics curriculum and textbooks. This gap underscores the need for comprehensive studies on the alignment of SPSs within educational materials. In this study, we therefore intended to contribute to this research field through the analysis of the physics curriculum and corresponding textbook regarding SPSs with certain attention to student autonomy.

Purpose of the Study

This study seeks to ascertain the alignment between the 9th grade Turkish physics textbook and its corresponding curriculum regarding SPSs representation and student autonomy. The research questions guiding this study are as follows:

1. How are SPSs represented in the 9th grade Turkish physics curriculum (2007), and what is the level of openness of the included skills in the curriculum?
2. How are SPSs represented in the 9th grade physics textbook published by the Turkish Ministry of National Education and what is the level of openness of the included skills in the textbook?
3. To what extent do the 9th grade physics curriculum and textbook align with each other in terms of the representation of SPSs and the level of openness in the included skills?

METHOD

In this document analysis, the method of content analysis, as outlined by Miles and Huberman (1994), is employed to systematically scrutinize written communications (Fraenkel & Wallen, 2006), facilitating the derivation of reliable and reproducible conclusions regarding the relationship between textual content and its broader contextual implications (Krippendorff, 2004). For this study, content analysis was applied to the 9th grade physics curriculum and textbook to examine the representation of SPSs. Categories for analysis were developed based on an extensive literature review on SPSs and student autonomy in given tasks which is aligned with the research questions. Following Krippendorff's (2004) recommendation, we determined the focus beforehand to ensure clarity in the coding process. This involved constructing a systematic analytical framework for SPSs, considering the student autonomy.

Data Sources

All students in four-year general, vocational, and technical high schools in Türkiye must take a 9th grade physics course before choosing a specialization. Since 2003, the Ministry of National Education (MEB) has provided free textbooks to ensure equitable access. These textbooks align with the national physics curriculum. The focus on the 9th grade physics curriculum (2007) is deliberate, as it was the first in Türkiye designed with specific skill objectives to foster scientific literacy. Because it was widely used, the 9th grade physics textbook published by MEB, in line with the 2007 curriculum, was chosen for this study.

Physics curriculum

The 2007 physics curriculum (MEB, 2007) was a milestone in Türkiye, developed collaboratively by faculty members in universities and teachers. It emphasized both content and skill development and introduced diverse teaching methodologies. Rolled out from 2009 and revised in 2013 to simplify its content, this study focuses on the original version. The curriculum's skill objectives were outlined under “The Learning Areas”, with content objectives divided into six main areas: “Nature of Physics”, “Energy”, “Properties of Matter”, “Force and Motion”, “Electricity and Magnetism” and “Waves”.

Physics textbook

This study analyzed the 9th grade physics textbook (MEB, 2010), approved by the Board of Education in June 2008 for nationwide use. Despite the availability of alternative textbooks, the MEB 2010 edition was chosen for its extensive adoption and long-standing presence in Turkish high schools. The textbook, comprising 261 pages, covers all necessary topics, from introductory to reference sections. Our analysis focused on the core chapters, excluding the introduction and reference, a total of 220 pages. These chapters include: Nature of Physics (36 pages), Energy (40 pages), Properties of Matter (34 pages), Force and Motion (52 pages), Electricity and Magnetism (28 pages), and Waves (29 pages).

SPSs Inventory

The codebook utilized for the content analysis was developed during the first author's Ph.D. study (Yılmaz-Senem, 2013) to identify SPSs in texts and distinguish student autonomy in given tasks. The development process spanned one year and incorporated expert opinions and a pilot study. Initially, SPSs were extracted from literature on SPSs, inquiry skills, and scientific process skills (Bailer, Ramig, & Ramsey, 2006; Buxton & Provenzo, 2007; Carin & Bass, 2001; Harlen & Qualter, 2009; Settlage & Southerland, 2007). The structure of the codebook was informed by analyzing Ph.D. studies that included the construction of codebooks (Binns, 2009; Phillips, 2006; Wang, 1998).

A comprehensive literature review on SPSs (Binns, 2009; Phillips, 2006; Wang, 1998) and levels of openness (Buck et al., 2008; Chinn & Malhotra, 2002; Heron, 1971) guided the inclusion of the introduction, unit of analysis, categories for SPSs with definitions, levels of openness, and examples from the textbook. The initial version of the codebook was reviewed by 19 experts in the fields of "science process skills", "assessment and evaluation", and "curriculum and instruction". They assessed it based on clarity, quality, proficiency of categories, and alignment with the study's objectives using an evaluation form. The final codebook, comprising 23 pages, includes an introduction, unit of analysis, coding rules, and categories for SPSs with coding examples (Yılmaz-Senem, 2013). An English version is available for researchers to use.

Analytical framework of SPSs inventory

In formulating the framework, two primary considerations were addressed: the selection of relevant SPSs and the definition of dimensions. A total of eleven SPSs were decided in secondary science education, as per research by Bailer, Ramig, and Ramsey (2006), Buxton and Provenzo (2007), Carin and Bass (2001), Harlen and Qualter (2009), and Settlage and Southerland (2007). They are categorized into two overarching groups:

1. Basic science process skills (BSPSs): observation, measurement, inference, classification, prediction, and communication.
2. Integrated science process skills (ISPSs): hypothesizing, defining and controlling variables, experimentation, data collection and interpretation, and modeling.

Furthermore, SPSs can be represented in text without expecting students to perform the skills themselves. Texts may provide information about the skills, such as defining observation or explaining the significance of constructing a hypothesis. This approach emphasizes the skills and is categorized under the "knowledge" dimension of the rubric. Drawing from the information-processing cognitive theory, which distinguishes between declarative and procedural knowledge (German et al., 1996; Marzano & Kendall, 2008), the "knowledge-based" dimension is divided into two domains. Table 1 illustrates the main structure of the SPSs Inventory (SPSI), outlining the dimensions.

Table 1. The Main Structure of the Framework (SPSI)

Dimensions			
	Declarative	Procedural	
Knowledge-based	Facts, vocabulary terms, and generalizations about the skills	Explains how to perform the skills	
	Level 1	Level 2	Level 3
Skill-based	Performs the skill by following a straightforward procedure	Focuses on the skill but does not perform	Plans and performs the skill

We draw on frameworks proposed by Herron (1971), Chinn and Malhotra (2002), and Buck et al. (2008) to define the level of openness for SPSs. Schwab (cited in Herron, 1971) introduced a scale of "openness" ranging from structured tasks to confronting students with raw phenomena. Herron (1971) expanded on Schwab's scale, adding a zero level where problems, methods, and interpretations are provided. This expanded scale, along with modifications by German, Haskins, and Auls (1996), provides a comprehensive framework. Chinn and Malhotra (2002) differentiate between authentic scientific inquiry and simpler tasks, categorizing them into simple experiments, observations, and illustrations. In order to evaluate student autonomy in SPSs, we have created a three-point scale for openness to determine whether students have the freedom to make decisions about a given task. To clarify, "Level 1" indicates that students are required to follow a straightforward, step-by-step procedure. "Level 2" indicates that students are asked to focus on the skill but are not required to perform it. "Level 3" indicates that students are expected to plan and carry out the skill. The level of openness for each skill was detailed in the "Scoring Rubrics of the Level of Openness for each SPS" provided in the Appendix.

Data Analysis

According to Krippendorff (2004), coding units are separate components used in analysis, and they must be distinct to ensure meaningful outcomes when it comes to meaning as well. In curriculum analysis, the unit was a sentence representing an objective and its explanations. Due to the characteristics of the curriculum, a content objective may be coded in more than one code in the same category but with different dimensions. However, it may contain only one SPS code from the same dimension. Textbook analysis used paragraphs, sentences, questions, activity steps, and visual elements. Context units, setting limits on information, included examples, projects, and tests. A unit of analysis may include different SPS codes, but not the same code more than once. A context unit can also contain more than one category but cannot contain the same code twice. If there was no representation of SPS in the context unit, it was coded as NA.

The researcher examined the textbook for intra-coder reliability twice in a span of two months. According to the comparison of codes done by the researcher at different times, Krippendorff's α was found to be 0.82. Inter-rater reliability, or reproducibility (Krippendorff, 2004), is reached when two or more coders working independently, under varying conditions, generate the same results by analyzing the same text. A chapter in the textbook was analyzed by a Ph.D student studying content analysis, and the inter-rater reliability coefficient, assessed using Krippendorff's α, was 0.83.

FINDINGS

Representation of SPSs in the 9th grade Physics Curriculum

First, skill objectives were coded individually, and 94 objectives were found to include SPS, whereas 22 of them did not include any SPS. There were 69 content objectives, and 17 of them did not involve any SPS. Due to the reciprocal relationship among the objectives, 509 units of analysis involved 253 SPS codes. Table 2 represents the frequency distribution of determined SPS in the curriculum.

Table 2. Frequency Distribution of SPSs in the 9th Grade Physics Curriculum

	Knowledge-based		Skill-based					
Skills	Dec.	Pro.	L1	L2	L3	C-S-E	*Total*	% (n=253)
Observing	2	2	0	1	3	2-6-2	*8*	*3.2*
Measuring	10	5	0	0	18	4-28-6	*33*	*13.0*
Inferring	0	0	0	0	0	0-0-0	*0*	*0.0*
Classifying	1	0	16	10	0	13-0-43	*27*	*10.7*
Predicting	0	0	0	0	0	0-0-0	*0*	*0*
Communicating	1	0	5	5	29	0-40-0	*40*	*15.8*
Hypothesizing	2	0	0	0	18	0-20-1	*20*	*7.9*
Defining/Contr. Var.	1	0	0	1	11	1-13-0	*13*	*5.1*
Coll./Interp.Data	1	0	2	17	38	17-41-0	*58*	*22.9*
Experimenting	2	4	0	0	26	11-21-1	*32*	*12.6*

	Knowledge-based		Skill-based					
Modeling	4	0	1	14	3	7-15-0	22	*8.7*
Total	*24*	*11*	*24*	*48*	*146*	*55-198-23*	*253*	
%(n=253)	*9.5*	*4.3*	*9.5*	*19.0*	*57.7*	*21.7-78.3-9.1*		

(Dec.: Declarative; Pro.: Procedural; L1: Level 1 in skill; L2: Level 2 in skill; L3: Level 3 in skill; C: Content objective; S: Skill objective; E: Explanation)

These SPS frequencies come from content objectives (C), skill objectives (S), and explanations (E), respectively. The total frequencies for each skill were not the sum of the codes because the repeated codes were counted once. The most underlined SPS was collecting and interpreting data, and the secondly emphasized one was communicating. Measuring, experimenting, classifying, and modeling were the ones covered on average. On the other hand, the skills of hypothesizing, defining and controlling variables, and observing were the least included, whereas the curriculum ignores inferring and predicting completely.

Collecting and interpreting data was the most included skill in the curriculum, and its representation emphasized student autonomy (38 out of 58 coding in level 3) by leaving room for them to be active. The content objectives, such as "Realizes that energy can be defined in different ways", and "Realizes that motion is a relative phenomenon", expected students to collect data about the concepts of energy, and motion, and draw a conclusion from the collected information. However, the curriculum revealed its intention of making students collect and interpret data by the cross-coding skill objectives to such content skills. For example, the skill objectives "Collects information from various sources to begin research by using pre-knowledge and experiences", and "Systematically records the data with the units which are gathered from observation and measurement" were highly attached to content skills. Therefore, it was underlined that students investigate new information, attain and synthesize data, distinguish them from unscientific ones, collect data via observations and measurements and analyze them by using statistics, and draw a conclusion based on the collected and analyzed data.

Adding the presentation of all kinds of investigation made the skill of communication the second most highly included skill (16%) in the curriculum. However, the skill of communicating was mentioned in only skill objectives and these objectives were cross-coded with the content objectives that teachers were expected to ask students to make presentations about their investigations. The skill of communicating was included in skill objectives such as "Prepares appropriate presentations for the determined aim", "Uses proper terminology in any type of communication about physics", and "Takes part in discussions based on physics and technology that can affect the future of a person, society, and environment". Since these skill objectives were linked to 40 content objectives, teachers should plan lessons that correspond to the relevant content objectives while fostering a presentation and discussion environment for students. The curriculum paid high emphasis on the skill of communication by the unique characteristics of feeding the content by the defined skill objectives.

Measuring was included in limited content objectives and the corresponding explanations in the knowledge dimension about the units of variables and their conversion of them. Such as the explanations given for content objectives "kHz, MHz units and their conversions are given", "Students are informed about the reasons of connecting circuit elements such as ammeter, voltmeter, and rheostat while constructing circuits where they will discover Ohm's law". It gave information about the units, and measuring and made students apply the rule of conversion of units. Only two skill objectives "Determine the appropriate measuring tool to measure variables" and "Make a sufficient number of measurements carefully with appropriate tools to reduce the error rate in measurement" involved measuring in the skill dimension. However, the frequency of measuring was increased because the skill objectives including measuring were linked to many content objectives.

The curriculum weakly involved controlling variables and observing but did not include inferring and predicting. Controlling variables were directly given in the skill objectives like "Defines the dependent, independent, and controlled variables in the problem or research" and attached to limited content objectives. Observing was pointed out in one skill and two content objectives but the frequency was very low. The skills of hypothesizing and inferring were only mentioned in the skill objectives but not in the content objectives. Hypothesizing was taken place directly: "Makes a testable hypothesis for a defined problem", and "Designs an appropriate solution for a defined problem". These skill objectives were attached to 18 different content objectives so the skill of hypothesizing increased to 7.8%. Inferring was indicated in two skill objectives but these objectives were not attached to any content objective, so the curriculum did not include it directly.

Representation of SPSs in the 9th grade Physics Textbook

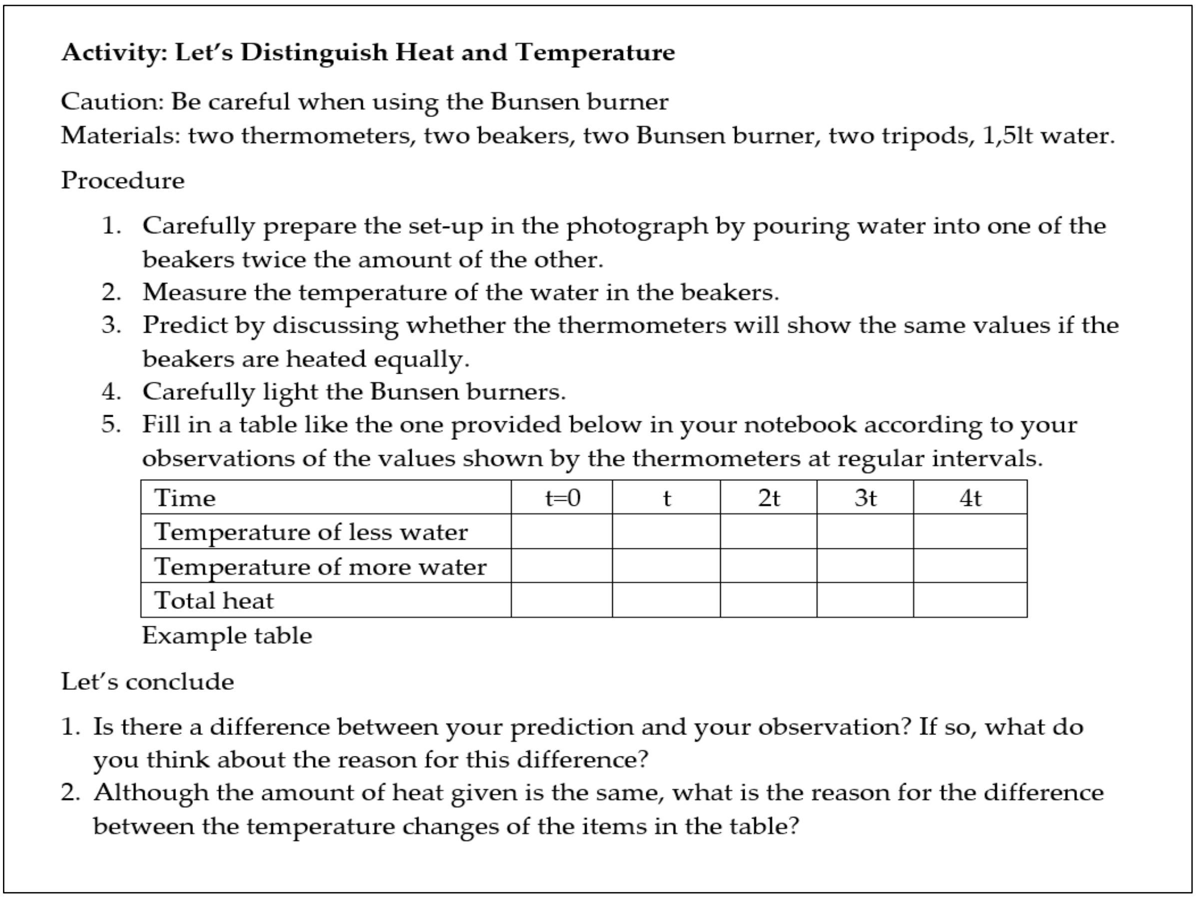
The physics textbook consisted of various parts such as "activity" in which students were supposed to find out intended knowledge via given tools and devices, "paragraphs" explaining the content, and "Let's Explore" in which students are supposed to investigate the concept to make a connection with daily life examples and share the findings in the classroom. These parts were determined as the context unit for the content analysis of the textbook and we obtained 1196 context units. The textbook had 744 units of analysis including SPS wherein 510 codes in the skill-based and 234 codes in the knowledge-based dimension and the textbook had 452 context units coded as NA. Table 3 demonstrates the frequency distribution of SPSs in the textbook. The content analysis showed that SPSs were mainly covered in the activities (34%) and the paragraphs of the texts (32%). Therefore, an example excerpt in this part was given from an activity. Before, Table 3 represents the frequency distribution of determined SPSs in the textbook.

Table 3. Frequency Distribution of SPSs in the 9th Grade Physics Textbook

	Knowledge-based		Skill-based					
Skills	Dec.	Pro.	L1	L2	L3	*Total*	% (n=744)	% (n=1196)
Observing	11	8	51	5	0	75	*10.1*	*6.3*
Measuring	26	64	37	21	0	148	*19.9*	*12.4*
Inferring	1	0	65	1	0	67	*9.0*	*5.6*
Classifying	42	0	28	9	0	79	*10.6*	*6.6*
Predicting	0	1	2	36	0	39	*5.2*	*3.3*
Communicating	1	0	40	0	1	42	*5.7*	*3.5*
Hypothesizing	6	2	1	3	0	12	*1.6*	*1.0*
Defining/Contr. Var.	1	2	2	12	0	17	*2.3*	*1.4*
Coll/Interp Data	4	1	109	11	25	150	*20.2*	*12.5*
Experimenting	20	12	1	0	0	33	*4.4*	*2.8*
Modeling	1	31	3	44	3	82	*11.0*	*6.9*
Total	*143*	*91*	*302*	*142*	*66*	*744*		
% (n=744)	*19.2*	*12.2*	*40.6*	*19.1*	*8.9*			
% (n=1196)	*12.0*	*7.6*	*25.3*	*11.9*	*5.5*	*62.2*		

(Dec.: Declarative; Pro.: Procedural; L1: Level 1 in skill; L2: Level 2 in skill; L3: Level 3 in skill)

Table 3 illustrates the frequency distribution of SPSs within the physics textbook, with values ranging from 1.6 to 20.2. When ranked by prevalence, "collecting and interpreting data" and "measuring" were the most frequently included skills. These were followed by "modeling," "classifying," "observing," and "inferring." Conversely, "communicating," "predicting," "experimenting," "controlling variables," and "hypothesizing" were among the least represented skills. The textbook predominantly emphasized the skill of "collecting and interpreting data," particularly within the skill-based dimensions, by instructing students to gather data from the internet. Specifically, data collection was heavily featured in the "Let's Explore" section (30 out of 150) and within various activities (62 out of 150), with provided procedural steps. Furthermore, students were required to complete tables, perform calculations, and construct graphs during these activities. The steps generally followed a consistent sequence: prediction, observation or measurement, and comparison of predictions with observed findings. This recurring structure within the activities is represented in Figure 1; an activity translated by the researcher from the 9th grade physics textbook (MEB, 2010).



Activity: Let's Distinguish Heat and Temperature

Caution: Be careful when using the Bunsen burner
Materials: two thermometers, two beakers, two Bunsen burner, two tripods, 1,5lt water.

Procedure

1. Carefully prepare the set-up in the photograph by pouring water into one of the beakers twice the amount of the other.
2. Measure the temperature of the water in the beakers.
3. Predict by discussing whether the thermometers will show the same values if the beakers are heated equally.
4. Carefully light the Bunsen burners.
5. Fill in a table like the one provided below in your notebook according to your observations of the values shown by the thermometers at regular intervals.

Time	t=0	t	2t	3t	4t
Temperature of less water					
Temperature of more water					
Total heat					

Example table

Let's conclude

1. Is there a difference between your prediction and your observation? If so, what do you think about the reason for this difference?
2. Although the amount of heat given is the same, what is the reason for the difference between the temperature changes of the items in the table?

Figure 1. Sample activity for the representation of repeated configuration in the activities

The skill of "measuring" was significantly more prevalent in the knowledge-based (61%) than in the skill-based (40%) dimension of the textbook. It primarily focused on procedural knowledge, detailing units of variables and conversion rules, as well as technical knowledge related to the operational use of measuring tools. The emphasis in the skill-based dimension was on following predetermined steps in procedural activities, limiting student autonomy in devising measurement approaches.

"Modeling" constituted 11% of all skills involved in the textbook, primarily presenting mathematical models of scientific concepts and their interrelationships. While the textbook provided extensive information on modeling (*f*=31), there were fewer instances (*f*=3) where students were tasked with constructing their own models. The focus was on explaining relationships among physical quantities using mathematical equations (*f*=44), with only a small number of activities (*f*=6) requiring students to construct models, and fewer (*f*=3) offering specific construction procedures.

The activities in the textbook built-in many SPSs in the "procedure" and "result" parts; "observing" and "predicting" were prominent in the procedure parts. The definition of observation, information about how scientists make observations were expressed (*f*=17) and students were asked to make observations but without defined purposes. Skills as predicting, inferring, communicating, collecting and interpreting data, and variable control were covered, but lacked formulation of research questions or complex observation chains. Prediction, while not emphasized in the knowledge-based dimension, featured prominently in activity procedures (f=30), typically involving simple predictions without consideration of new variable effects. In the "Let's Conclude" parts of the activities, students were expected to interpret data (f=62) and make inferences (f=39). However, the textbook did not give room for students to employ reasoning by having explanations just after the activities. Moreover, the inferences could be made based on the given mathematical equations that make students employ deductive reasoning.

Skills of communicating, predicting, experimenting, controlling variables, and hypothesizing took place in the textbook in small percentages. Students were requested to share their findings (f=41) in the "Let's Explore" part (f=29) in which they searched on the internet or via books. Students were also asked to present their findings in the activities (f=2) to compare them. Nevertheless, the percentage of student autonomy was very limited for these skills since there was no task asking students to generate scientific research and share their findings with a personalized method. Conversely, the textbook provided information on experimenting, primarily in the chapter on the Nature of Physics (f = 18). Not even one activity required the students to plan, carry out, or even consider designing an experiment.

Comparison of the Curriculum and the Textbook on the Representation of SPSs

We aimed to determine the involvement of SPSs and student autonomy in using SPSs in the physics curriculum and the textbook. Additionally, we sought to establish the alignment between the curriculum and the textbook regarding SPSs and student autonomy. To compare SPSs involvement and student autonomy in different documents, we calculated the percentages of each skill's representation among all included SPSs. Hence, we compared the weight of each skill in two documents, and Table 4 represented the percentages of SPSs distribution in the dimensions together. Moreover, the difference in percentages was calculated for each skill by subtracting the percentage of the skill in the curriculum from the one in the textbook. Table 4 also shows the differences in percentages of total involvement of SPSs in each dimension between the curriculum and the textbook. If the difference is positive, it means the percentage of that skill in the curriculum was larger than the percentage in the textbook. Conversely, if the difference is negative, the textbook involved that skill more in percentage than the curriculum involved.

Table 4. Distribution Percentages of SPSs in the 9th Grade Physics Curriculum and Textbook

		Knowledge-based		Skill-based				*The diff. in % for total SPS*
Skills		Dec.	Pro.	L1	L2	L3	Total	
Observing	C	0.8	0.8	0.0	0.4	1.2	3.2	*-6.9*
	T	1.5	1.1	6.9	0.7	0.0	10.1	
Measuring	C	4.0	2.0	0.0	0.0	7.1	13.0	*-6.9*
	T	3.5	8.6	5.0	2.8	0.0	19.9	
Inferring	C	0.0	0.0	0.0	0.0	0.0	10.7	*0.1*
	T	0.1	0.0	8.7	0.1	0.0	10.6	
Classifying	C	0.4	0.0	6.3	4.0	0.0	10.7	*0.1*
	T	5.6	0.0	3.8	1.2	0.0	10.6	
Predicting	C	0.0	0.0	0.0	0.0	0.0	0.0	*-5.2*
	T	0.0	0.1	0.3	4.8	0.0	5.2	
Communicating	C	0.4	0.0	2.0	2.0	11.5	15.8	*10.2*
	T	0.1	0.0	5.4	0.0	0.1	5.6	
Hypothesizing	C	0.8	0.0	0.0	0.0	7.1	7.9	*6.3*
	T	0.8	0.3	0.1	0.4	0.0	1.6	
Defining/Contr. Var.	C	0.4	0.0	0.0	0.4	4.3	5.1	*2.8*
	T	0.1	0.3	0.3	1.6	0.0	2.3	
Coll./Interp. Data	C	0.4	0.0	0.8	6.7	15.0	22.9	*2.7*
	T	0.5	0.1	14.7	1.5	3.4	20.2	
Experimenting	C	0.8	1.6	0.0	0.0	10.3	12.6	*8.2*
	T	2.7	1.6	0.1	0.0	0.0	4.4	
Modeling	C	1.6	0.0	0.4	5.5	1.2	8.7	*-2.3*
	T	0.1	4.2	0.4	5.9	0.4	11.0	
Total	C	*9.5*	*4.3*	*9.5*	*19.0*	*57.7*	*100*	
	T	*19.2*	*12.2*	*40.6*	*19.1*	*8.9*	*100*	
Difference in %		*-9.7*	*-7.9*	*-31.1*	*-0.1*	*48.8*		

(Dec.: Declarative; Pro.: Procedural; L1: Level 1 in skill; L2: Level 2 in skill; L3: Level 3 in skill; C: Curriculum; T: Textbook)

The skill of collecting and interpreting data exhibited the highest proportions and a congruent distribution across both documents. The textbook meticulously mirrored the incorporation of this skill within its activities, requiring students to systematically transform data into various formats, including tables, graphs, and charts. First, students had to fill in tables. Afterward, they had to make graphs and use the graphical features to derive quantitative values (Figure 1). On the other hand, the two documents differed in their approach to student autonomy. Although both documents emphasized the importance of collecting and evaluating data, the textbook did not include exercises that encouraged students to collect data from their experiments and draw conclusions from their findings. The textbook did not allow students to choose their data collection or organization methodology, while the curriculum emphasized. Additionally, the textbook did not provide opportunities for students to identify research variables, use caution when manipulating them, and conduct multiple trials and controls, which are essential aspects of the curriculum.

The curriculum intended to make students design their experiments to test a hypothesis (10%) and present their observations, and findings of their scientific research (16%). On the other side, the textbook involved activities that were organized to make students observe, collect data, and draw a conclusion regarding observations and measurements, but none started with a research question nor let students formulate hypotheses. Similarly, the skill of communicating (5% in level 1 and 0.1% in level 3) took place in the textbook asking students to prepare proper presentations for the determined purposes, use terminology in any type of communication about physics or share their findings from the internet, and books. However, these findings were not the ones coming from students' observations, designs for experiments, and trials. The textbook consisted of many activities without any research questions formulated but only asked students to follow the steps.

According to Table 4, the skills of observing, measuring, inferring, and predicting were involved in the textbook with higher percentages than they were involved in the curriculum. Moreover, the curriculum even did not include inferring and predicting. The textbook made students observe, measure, infer, and predict through the step-by-step procedures given in the activities. However, it did not allow students to employ multiple forms of argument or predict the possible effects of a new variable. Students were expected to predict simple observations or employ inductive reasoning for simple arguments, besides, the explanations were directly given just after the tasks asked students to make predictions or inferences in the textbook. Figure 2 represent a general view how much attention paid to student autonomy in the curriculum and the textbook.

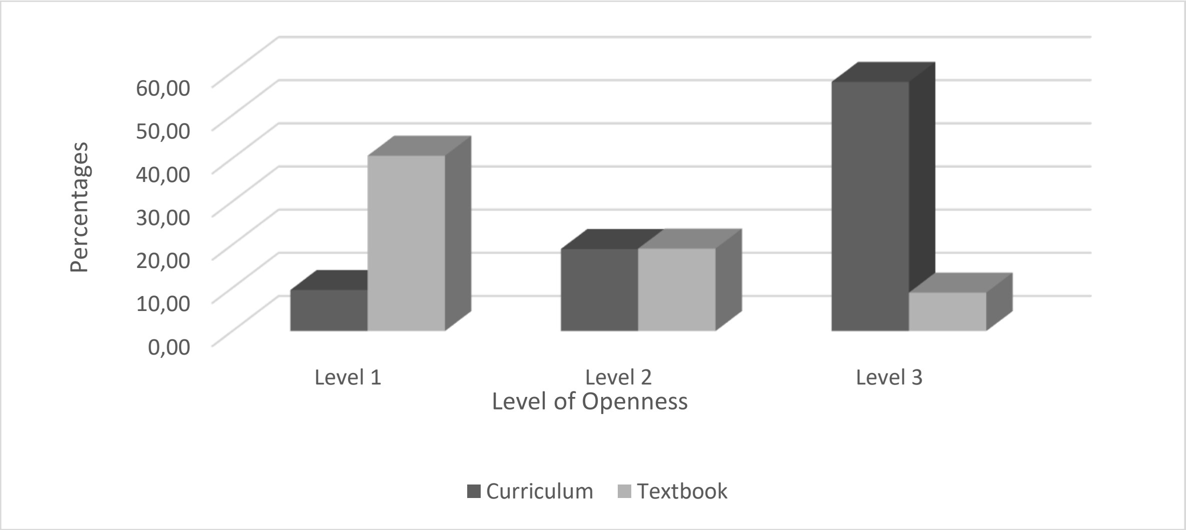


Figure 2. Percentages representing levels of openness of SPSs in the curriculum and the textbook

From the general perspective both the curriculum and the textbook involved SPSs mainly in the skill-based dimension, nevertheless, the percentage of inclusion in the skill-based dimension in the curriculum was higher than the percentage in the textbook. Inappropriately, they did not have consistency in student autonomy; Figure 2 shows that there were large differences between the percentages of the curriculum and the textbook in level 1 and level 3. These differences showed that the textbook gave less room for students to plan their own investigations while performing SPSs whereas the curriculum addressed the autonomy of students.

DISCUSSION

The purpose of this study was to ascertain the alignment between the 9th grade Turkish physics textbook and its corresponding curriculum regarding SPSs representation and student autonomy. Having dimensions and the level of openness defined for each skill, the SPSI provided criteria to distinguish student autonomy when performing the skills. When content is analyzed concerning the verbs as an indicator of the skill, the quality of the task cannot be determined. That is impossible to detect SPSs in texts by counting the verbs “observe”, “watch”, “take notes” or by searching for the definition of “use senses to describe the observed object optimally” attributed to an indication for observing unless it starts with a guiding question (Buxton & Provenzo, 2007). Similar to the conceptual frameworks addressing inquiry (Chinn & Malhotra, 2002) and scientific literacy (Chiappetta, Fillman, & Sethna, 1991), our framework that addresses specifically SPSs expresses the important conditions that supply student autonomy about the skills. NVIVO 10 was used for the content analysis which makes possible to keep a huge amount of data and turn back any code at any time. To examine how well the content analysis by SPSI produces reliable results, another coder analyzed the textbook and Krippendorff’s α was found 0.83. We would suggest that SPSI constructed for this study can be used to reflect the quality of written materials regarding student autonomy.

Our findings revealed that the physics curriculum signified mostly collecting and interpreting data, communicating, measuring, and experimenting, however, the skills of observing, inferring, and predicting were ignored by the curriculum. This result is consistent with the studies that overwhelming emphasis on BSPSs over ISPSs among curriculum is also determined for the 2005, 2013 and 2018 Turkish science curricula (Bağcı-Kılıç et al., 2008; Duruk et al., 2017; Yapıcıoğlu, 2021). This result may be due to the nature of the SPSs. There is a hierarchical relationship between the categories of skills. ISPSs include some BSPSs such that experimenting includes the collection of data attained by observing, inferring, and predicting implicitly (Carin & Bass, 2001). The analyzed physics curriculum, the first one in Türkiye that includes objectives for skills, had a novel emphasis on scientific literacy like NSES (NRC, 1996; 2012). However, considering the curriculum as “the start of a cascade of interpreted curricula” (Carr et al., 2001, p. 25), this change was expected to cause a chain of changes in textbooks to give prominence to skills.

The results of the content analysis indicated that the physics textbook involved predominantly measuring skill from BSPSs and collecting and interpreting data from ISPSs and involved frequently observing, classifying, inferring, and modeling. However, these skills appeared repetitively in the activities that provided step-by-step procedures leaving no space for students to design any observation, experiment, or even a method to make measurements. Activities having components “materials”, “procedure”, and “conclusion”, asked students just to follow the steps by using given materials to attain the goals set in the procedure part. Although our result cannot be comparable to the results of other studies in terms of the framework, this result -having highly structured tasks- is consistent with the literature in science education (Chinn & Malhota, 2002; German et al., 1996; Park, 2005; Soyibo, 1998; Tamir & Lunetta, 1978). Moreover, “cookbook” tasks in science textbooks are even oversimplified such Chinn and Malhotra (2002, p. 200) stated that “no activity allows students to generate their own research question” and German et al., (1996) underlined that students were not given any opportunity to formulate a hypothesis, design any observation or measurement. The textbook provided most of the answers to the activities and tasks prepared for students to observe, investigate, and infer on the same page, which means students get the answer without performing them. However, it is well known that activities whose result is already known and include step-by-step procedures do not develop students’ SPSs (Soyibo, 1998). This result shows that textbooks need much work to give students much more space and serious responsibilities while performing the skills.

Our research endeavor aimed to scrutinize the congruence between the curriculum and the corresponding textbook concerning the integration of SPSs and depth of student autonomy. We revealed a discernible incongruity in the manifestation of these skills across various dimensions and levels of openness in skill dimension. While the curriculum delineates a comprehensive educational roadmap comprising objectives, content specifications, instructional resources, and assessment strategies, textbooks function as instructional aids fashioned in alignment with the curriculum's objectives. Notably, textbooks wield considerable influence in shaping instructional practices, often exerting a formative role in curriculum enactment (Ornstein, 1994). Our focus lay not in direct comparison but rather in delineating their coherence by scrutinizing the distribution of SPSs within the curriculum and textbook and, crucially, student autonomy. Although the curriculum endeavors to cultivate students' proficiency in SPSs by elucidating these skills and underscoring their significance, it accords greater emphasis on fostering student agency in decision-making within instructional tasks. However, despite the curriculum's articulation of these skills, the textbook fails to fully realize the curriculum's intent of fostering student autonomy in skill application.

LIMITATION AND SUGGESTIONS

In alignment with this study, the following limitation of the study and recommendations for future research on SPSs are proposed.

The study was completed in 2013, and since then, both the curriculum and textbooks have undergone revisions. Therefore, the results reflect the educational context as it was at that time and may not fully represent the current state of physics education in Türkiye. Nonetheless, the study provides insights into how the first skill-oriented physics curriculum of Türkiye portrayed SPSs and fostered student autonomy, as well as how the corresponding physics textbook addressed these aspects at that time. These findings can serve as a valuable resource for future research aiming to compare the representation of SPSs in current physics curricula and textbooks.

This study was completed in 2013, however the systematic framework developed for assessing SPSs, with a focus on student autonomy, remains relevant and novel. Future research should apply this framework to the current physics curriculum and textbooks to determine whether recent modifications have improved alignment with the intended emphasis on student autonomy. Additionally, this framework can be utilized in other science-related contexts beyond physics and across various grade levels, ensuring a comprehensive approach to fostering science process skills and student autonomy.

Textbook authors should adapt their content to reflect ongoing changes in the curriculum while preserving activities that foster independent scientific inquiry. Incorporating flexible, open-ended activities can help align textbooks with the evolving educational goals. The content of textbooks should be updated to reflect changes in the curriculum. It's important to keep activities that encourage independent scientific inquiry while incorporating flexible, open-ended activities to meet evolving educational goals. Longitudinal studies should be conducted to assess how curriculum changes affect students' SPSs and autonomy in the long term. This can provide valuable data on the effectiveness of past and present educational practices.

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APPENDIX

Scoring Rubrics of the Level of Openness for each SPS

Skills	Definition	Level 1	Level 2	Level 3
Observing	Collecting data by using all appropriate senses and instruments that extend the senses to gather information, and describe a process, an object. It starts with a research question or guiding question.	Observes variables without any purpose. Observations are straightforwardly related to research questions. Observes prescribed features.	Poses a research question and plans to make an observation. (Does not make observations, but there is a cognitive process to planning an observation.)	Observes with a research question or on purpose. Observations are related to research questions by complex chains of inference.
Measuring	Attaining a quantity from a proper measuring tool to describe objects. Describing objects using standard or non-standard units.	Students are told what to measure, and it is usually a single outcome variable. Students are told how to measure, and it is given straightforwardly.	Thinks about a research question and plans to make measurements. Plans how to measure as a cognitive process.	Incorporates multiple measures of independent, intermediate, and dependent variables. Decides how to measure and/or develop measurement tools through a research question.
Inferring	Drawing a conclusion based on observations. Interpreting the events with experience and knowledge.	Employs inductive/deductive reasoning for simple arguments. The explanation is given just after in the text. Comprehends the provided explanation linking the theory to the data.	Thinks about reasoning and comprehend that reasoning is uncertain. Students are told that “Scientists employ multiple forms of argument” and they are given examples of scientists’ reasoning.	Employs reasoning and multiple forms of argument. When the explanations are not given just after in the textbook. Employs various modes of reasoning to derive a conclusion from an experiment.

Scoring Rubrics of the Level of Openness for each SPS (cont.)

Skills	Definition	Level 1	Level 2	Level 3
Classifying	Group the objects and/or events according to similar or different specifications. It is important to depend on knowledge and/or the data which were obtained by observations. It is important to have a clear classification parameter.	Determines common properties of simple objects/events. Determines different properties of simple objects/events. Puts in order events/objects according to their relationship which is simple.	Discusses similar properties of known classification groups. Discusses different properties of known classification groups. Discusses a specified parameter in a known classification.	Classifies objects/events according to the parameter(s) that they identified by them.
Predicting	Declaring an effect of a future event based on a pattern of evidence.	Makes a straightforward prediction about a simple observation task.	Makes many different predictions about observations of a research question.	Predicts about possible effects of a new variable by using the relationship of known variables.
Communicating	Transmitting information to other people in any formats. Sharing ideas with other people in verbal/written formats. Sharing and discussing on the whole or a part of a research.	Presents the findings of their search based on books, the internet, etc.	Listens and discusses others' scientific findings and thoughts.	Presents and discusses observations, design, and findings of her/his experiments. Prepares a report for her/his scientific research, experiment, observation.
Hypothesizing	Building a clarification for a related set of observations. It is important to write a testable hypothesis regardless of being true.	Students are asked to generate a hypothesis without any observation.	Evaluates supplied or created hypotheses in terms of the properties of a good hypothesis. Decides if a hypothesis can be tested.	Formulates a testable hypothesis for research based on a related set of observations.

Scoring Rubrics of the Level of Openness for each SPS (cont.)

Skills	Definition	Level 1	Level 2	Level 3
Controlling Variables	Determining all effecting factors (variables) for an experiment. Changing only independent variable, which will be tested. Controlling all other variables excluding independent one.	Students are told which variables to control for and/or how to set up a controlled experiment. Students are told how to control the variables of a controlled experiment.	Defines dependent, independent, and controlled variables for a controlled experiment. Decides how to control the variables of an experiment.	Defines dependent, intermediate, independent, controlled, and uncontrolled variables. Employs one or multiple controls.
Collecting and Interpreting Data	Gathering qualitative/quantitative data depending on prediction and hypothesis. Organizing and transforming the data into different forms (table, graph, and chart) to reach a valid conclusion.	Students are told to collect data: record what they see. Collects data from one set of observable results with conclusions about those observable results.	Organizes collected data: clean data from unnecessary ones. Inquiries to convert from one form to another form (text, graphics tables, charts, etc.).	Collects and interprets data from trials made with variables. Coordinates theoretical models with multiple sets of complex, partially conflicting data. Draws a conclusion based on collected data.
Experimenting	Testing the hypothesis or predictions, in such a way that making an effective plan to detect the effect of a selected independent variable on the dependent variable.	Follows simple directions of an experimental procedure (step-by-step).	Thinks about how to design an experimental setup to test a hypothesis.	Designs an experimental setup to test a hypothesis.
Modeling	Comprehending and using properly physical, conceptual, and mathematical models. A model is an understandable, concrete, and visual format of a concept, event, fact, or system.	Students are told to make a previously constructed model following a step-by-step procedure.	Explains the relationship between events/concepts by using previously constructed models.	Makes an original model of a new concept or event without a given procedure. Devises analog models to address the research question.