

Science Curriculum Objectives' Intellectual Demands: A Thematic Analysis

Yilmaz Soysal^{1*}

¹Istanbul Aydin University, Higher Education Studies Application and Research Center, Turkey

*Corresponding Author. yilmazsoysal8706@gmail.com

ABSTRACT Science curriculums and curricular materials are essential guidelines in materializing effective science teaching. The primary goal of the current study aims to present a thematic analysis of the last three elementary and middle school science curriculums objectives released in 2013, 2017, and 2018 to determine whether they provide a base for science teachers to design intellectually demanding instructional tasks. This study conducted an in-depth document analysis to describe the curricular themes and objectives' intellectual demands beyond a mere description. Moreover, a critical document-based thematic analysis achieved a call for an in-depth interrogation of the intended science curricula. The current study reveals that the explored science curriculums mainly include physics-related and biology-related topics and chemistry-related topics. There is less place for the issues related to astrophysics and earth sciences. Although three curricular changes (2013, 2017, and 2018) were actualized to enrich the science curriculums' scope, intellectual capacity, and thematic variation, the conceptual emphasis seemed to be strictly copied over the years. The curriculums under examination appeared to let the teachers design high intellectually demanding tasks to teach science knowledge and epistemic practices, however, to a certain extent. It is concluded that the sharp decreases in the number of objectives observed in the abstraction zone may hinder teachers from generating teaching environments where students can transfer acquired knowledge and practices to external contexts. Educational recommendations are offered in the sense of curriculum development and teacher education.

Keywords Science Curriculum, Curricular Objective, Intellectual Demand, Instructional Task, Science Teacher

1. INTRODUCTION

1.1. Background of the study

Developing countries like Turkey have invested heavily in schooling systems since it is considerably related to the economic development and quality of social life. However, despite the efforts around education on both national and international scales, Lewin (1993) indicates some severe issues in instructional quality and students' intellectual acquirements in general. Brown-Acquaye (2001) directly states that these general and particular problems are of either an appropriateness or implementation issue of curricula in general and science curricula in particular. Educational policymakers see the value of science education in economic growth and technological modernization to support the problems (Koh, Tan, & Cheah, 2008). Unfortunately, most of the developing nations try to use a version of the Western-regulated curricula system by, most of the time, simply adapting it into their educational context (Cross et al., 2020).

On a national and international scale, the curriculum development process has been considered a problematic

duty for educators and educational policymakers (Cross et al., 2020). For instance, curriculum reforms should incorporate clear research-based evidence or school system outcomes. However, Çalik and Ayas (2008) reported that over a relatively short time, four major revisions and 11 different versions of the Turkish science curriculum were released from 1924 to 2005, with six since 1968. Thus, Çalik and Ayas (2008) concluded that Turkish science teachers have never had a chance to implement a particular curriculum entirely before replacing it with a new version. Similarly, as Turkish science teacher educators, we have never actually managed to conduct careful research to fully delve into a being implemented curriculum before it was changed with a novel version exemplified in the present study (e.g., 2013, 2017, and 2018 curriculum).

There has been an ongoing call for educators and educational policymakers to rehabilitate the schooling systems by fostering the curricular objectives and contents. Firstly, curriculum development must be considered a

Received: 21 June 2021

Revised: 2 October 2021

Published: 1 March 2022

needs-based process. Secondly, local experience is essential in shaping a science curriculum's frame. Thirdly, curricular objectives, contents, and teaching strategies imposed by curriculums should be compact with an appropriate and supporting assessment and evaluation regime. Fourthly, teacher professional development should accompany an effort to enrich a curricular paucity. Finally, curriculum development, implementation, and assessment take time since it is a longitudinal process (Cross et al., 2020).

1.2. Justification for the Study and Theoretical Framework

In the context of Turkish education, radical changes in science curriculums were actualized for elementary and middle school (grades 3-8) two decades ago. These newly designed science curriculums favored co-constructivist pedagogies to teach science concepts and practices (e.g., Çalik, Alipaşa, & Coll, 2007; 2008). Thus, Turkish science teachers could practice intellectually effective instruction at the classroom level to foster students' cognitive and affective outcomes in light of the reform-based curriculums. One of the prominent parts of an intellectually demanding classroom setting is the task (as an *instruction unit*; Tekkumru-Kisa, Stein, & Schunn, 2015; Tekkumru-Kisa, Schunn, Stein, & Reynolds, 2019). Thus, there would be a concrete interaction between intellectually demanding tasks and students' acquisition of science concepts and epistemic practices. The present study conducted a thematic or content-based analysis of the objectives of the elementary and middle school science curriculum. It is needed to determine whether the curriculums provide pedagogic opportunities for Turkish science teachers to design and conduct cognitively demanding in-class implementations.

Morphology of in-class tasks implies a sophisticated relationship between science teachers' pedagogy and curricular materials (Dela Fuente, 2021; Elizabeth, Fred, Janssen, & Van Driel, 2016). Understanding this relationship attaches importance since an intended curriculum regulates how teaching and learning occur in the classroom (Kim, 2019). Curriculums are pedagogically guiding collections or intended planning tools (Schmidt et al., 2001). This implies that curriculums are a springboard in determining students' opportunities to learn (Milner, 2011). A curriculum is "a plan for the experiences that learners will encounter, as well as the actual experiences they do encounter" (Remillard & Heck, 2014). Thus, science teachers should design and implement intellectually demanding tasks for more skill-based instruction based on the objectives in a curriculum.

The intellectual capacity of a curriculum is explicitly related to its objectives' demands. A curriculum's objectives may have fluctuations regarding academic demands embedded in them implicitly. For example, recalling an event's date differs from *paraphrasing* a concept or *analyzing* an argument regarding cognitive effort an individual

displays. Examining a curriculum's intellectual capacity links the teaching processes with a curriculum's objectives (Lee, Kim, & Yoon, 2015; Lee, Kim, Jin, Yoon, & Matsubara, 2017). A curriculum may provide diverse educational opportunities to science teachers to sustain a rhythm (Dela Fuente, 2021; Dela Fuente & Biñas, 2020; Mortimer & Scott, 2003) when designing and implementing lower-demanding or higher-demanding tasks for optimal student learning. The *cognitive load* of a curriculum is hidden in its objectives and should sustain a balance regarding intellectual correspondence on the side of students (Lee et al., 2015; 2017). It would facilitate working with a *homogenous* science curriculum that harmonizes its objectives with lower, moderate, and higher cognitive demands. A *heterogeneous* curriculum incorporates an irregular dispersion of high, medium, or low intellectually demanding objectives. It is unlikely to implement a curriculum with low cognitively demanding objectives effectively. On the other hand, it is still problematic to implement a curriculum incorporating high cognitively demanding objectives pervasively.

Consequently, presumptive intellectual demand embedded in the objectives of a curriculum should disperse homogeneously to support the highest student acquisition of science concepts and practices. Therefore, this study explored whether the 3-8 grade science curriculums implemented in the 2013, 2017, and 2018 years in Turkey had an internal balance regarding the cognitive demands embedded in their objectives, prompting teachers to plan and conduct instructional tasks to teach elementary, middle school science.

1.3. Curricular objective, instructional task, and intellectual demand

The central term of the present study is intellectual demand that is the level or kind of thinking required of students to successfully engage with a science task (Tekkumru-Kisa et al., 2015). Intellectual demand is more about what learners must know and do and productive disciplinary engagement through in-class assignments formatted by the curricular objectives (Tekkumru-Kisa et al., 2015). Increasing intellectual demand presses students to operate several psychological or cognitive abilities, functions, or variables (psychometric variables). The task's sophistication predicts a task's intellectual demand. In the present study, three aspects of science teaching (curricular objective, instructional task, intellectual demand) are linked.

By reinterpreting curricular objectives, science teachers define the boundaries of in-class implementations that may create diverse cognitive demands on the side of students. Examples make the point mentioned above clearer.

Objective-1: "A student can describe the basic functions of the sense organs."

Objective-2: “A student can do experiments to compare the response rate of different sense organs while reacting to an event requiring rapid reflexes.”

In the first objective, students should listen to the teacher, comprehend the functions of the sense organs, and provide relevant examples of the functions based on their everyday observations. However, the second objective would demand different levels and kinds of student thinking (Tekkumru-Kisa et al., 2015). In the second objective, science teachers should initially encourage students to negotiate which sense organ may be faster than reflexing to a rapidly occurring event compared to the others. Moreover, science teachers should guide students to construct hypothetical claims and researchable questions before data collection, analysis, and interpretation. Then, teachers should guide students to design and conduct reliable and valid experiments to compare and contrast different sense organs' reflex rates by collecting data from different individuals. In addition, students have to communicate their experimental findings with their classmates. There will be counter-arguments to rebut a group's data-based interpretations, and the group has to convince other groups that their argument is valid and explanatory. In the second objective, students have to handle more cognitive work/effort to understand how the sense organs function in the presence of the different real-life events (e.g., catching a free-falling mass quickly by seeing or hearing). In the second objective, there will be more argumentative discourse within a possibly challenging learning environment where different student groups might draw contradictory conclusions even though they address similar research questions. In the second example, students listen to the teacher and capture what is being uttered. In addition, they have to listen to their classmates, generate evidence-based claims, protect their arguments from others' refutations, criticize others' claims, etc. These cognitive operations will therefore demand higher or *highest* intellectual activity from students. In conclusion, a curricular objective's underlying pedagogical aim profoundly influences teachers' execution of an instructional task. This is explicitly related to what a science teacher may do with an objective that incorporates low or high cognitive, intellectual correspondence when transformed into a teaching process.

The outcomes of the present study will be helpful for teachers to realize in what ways and to what extent science curriculums' objectives permit them to produce high and low cognitively demanding instructional settings. This study is also instrumental for curriculum developers to develop a holistic portrayal of the intellectual demands embedded in the examined curricular objectives. In the national context, most studies dedicated to a document-based analysis of the curriculums tended to analyze only a curriculum in an isolated manner from others (e.g., Aktan, 2019; Aydin, Ayyildiz, & Nakiboğlu, 2019; Cangüven, Öz,

Binzet, & Avcı, 2017; Zorluoğlu, Kizilaslan, & Sozbilir, 2020). The current study takes a longitudinal style. The last three curriculums' objectives were investigated and constantly compared across the years (e.g., 2013, 2017, and 2018) regarding the potential intellectual demand.

Apart from the previous research, in the present study, the *thematic/conceptual background* of the objectives was considered to clarify how their intellectual demands vary based on different science content areas (e.g., physics-related objectives, chemistry-related objectives; biology-related objectives, the objectives found for earth sciences and astrophysics content areas). Wan and Lee (2020) proposed that a curriculum can be examined thematically regarding different aspects such as contents' coverage, focus, sequencing, and emphasis. The current study considers especially coverage, focus, or emphasis on science content areas' curricular objectives. *Coverage* implies selecting many specific science concepts in a curriculum (Wang & McDougall, 2019). More significant numbers of topics indicate soft focus and vice versa. Thus, in the present study, apart from the previous studies (e.g., Aktan, 2019; Aydin et al., 2019; Cangüven et al., 2017; Zorluoğlu et al., 2020), it was also possible to detect whether the objectives' cognitive demands fluctuate across the different content areas or science themes/concepts. There are a few methodologically sound studies on intellectual demands of curricular objectives created in the sense of different science contents areas (e.g., Wan & Lee, 2020).

2. METHOD

2.1. Research Design

The current study was a document analysis (Karppinen & Moe, 2019). The researcher's purpose was not to merely describe the curricular themes and objectives' intellectual demands. Instead, a critical exploration of them was the purpose. In the present study, the document analysis approach was used as a thinking tool to detect the written data trends systematically (e.g., intended curriculums released in 2013, 2017, and 2018). By a theory-laden document analysis, the curriculums' internal potential in creating spaces for science teachers to plan and implement both low, moderate, and high intellectually demanding tasks for meaningful science teaching was explored in the present study. The analysis of the written documents was theory-laden since specific pedagogical lenses, e.g., the interaction between curricular objective, instructional task, and intellectual demand interpreted above, were treated to describe the curriculums differently to make them more *readable* to the external users.

2.2. Data collection, analysis, and trustworthiness

The data corpus was the intended elementary and middle school science curriculums released in 2013, 2017, and 2018, gathered through official correspondence with the national education ministry. The data analysis included six steps detailed below.

Extraction: First, the curriculums' objectives were organized, and the unit of analysis was decided as an objective-based examination. The curriculums included objectives classified in cognitive, affective, and psychomotor domains in line with the revised Bloom taxonomy (Anderson et al., 2001) detailed below. A substantial amount of the objectives, more than 90% examined in the present study, were placed in the cognitive domain category. This step was executed as a selection process to pick out the objectives in the cognitive domain category. Finally, being selected objectives were controlled and organized for an in-depth examination. Two researchers performed the extraction process, and the inter-coder reliability was 91%.

Thematic analysis: In the present study, to detect the discipline-based differences, first, the objectives were categorized regarding the science content areas. The curricular units' titles (e.g., "let us know the force") guided this initial and broader classification. Then, for a more fine-grained description, individual objectives were examined to refine the key concepts or keywords embedded in them (see Table 4 for detailed examples). Next, for each curricular unit and sub-units, several keywords were reproduced based on the contents of the objectives. Finally, the extracted keywords were recategorized around the different science content areas.

Selection of the tool for analyzing the objectives' intellectual demand: The revised Bloom taxonomy (Anderson et al., 2001) was selected to use as a thinking tool in mapping out the possible intellectual demands embedded in the objectives. There are, of course, other versions of categories (e.g., Marzano and Kendall's (2006) taxonomy, the Smith's taxonomy for mathematics by taking the rationality of Bloom's taxonomy into account (Smith et al.,

1996), the structure of the Observed Learning Outcome (SOLO) taxonomy (Biggs, 1995)) to examine a curriculum's objectives' intellectual demands.

The RBT was selected among other assessment tools for some reasons. First, the RBT has been more familiar to researchers to use as an assessment tool (e.g., Elmas et al., 2020; Toledo & Dubas, 2015). Several teacher educators have also comprehended it more precisely to present a panoramic picture of an intended curriculum's intellectual capacity. Second, the RBT permits researchers to examine a curriculum both analytically and holistically. Analytically, individual objectives' intellectual capacity can be more knowable with the RBT. By the holistic manner, e.g., coding and quantifying intellectual capacity, the trends in the objectives' structural and pedagogic characteristics can be traceable or knowable for their users. In addition, the RBT has been central for different research purposes. For example, apart from the curricular studies, the Author (2020) used the RBT to analyze a science teacher's in-class questions' intellectual demands that might be instrumental in triggering higher-order student reasoning and intellectual contributions to classroom talks.

The RBT consists of two dimensions as knowledge and cognitive processes (Anderson et al., 2001). In the present study, the cognitive process dimension was used for more analytical and fine-grained analysis of the objectives. The cognitive process dimension includes six categories: remember, understand, apply, analyze, evaluate, create, and 19 sub-categories characterized by specific action verbs. There is a hierarchy between the categories regarding intellectual demand (Anderson et al., 2001). A low intellectually demanding category (understand) occurs before achieving a high cognitively demanding category

Intellectual demand	Cognitive process	Definition
Perception	Remember (recognizing, recalling)	Retrieve knowledge from long-term memory
	Understand (interpreting, exemplifying, classifying, summarising, inferring, comparing, explaining)	Construct meaning from instructional messages, including oral, written, and graphic communication
Conception	Apply (executing, implementing)	Applying a procedure to a familiar task
	Analyse (differentiating, organizing, attributing)	Break material into its constituent parts and determine how the parts relate to one another and an overall structure or purpose
Abstraction	Evaluate (checking, critiquing)	Make judgments based on criteria and standards
	Create (generating, planning, hypothesizing)	Put elements together to form a coherent or functional whole; reorganizing elements into a new pattern or structure

Figure 1 The revised Bloom Taxonomy (Anderson et al., 2001)

(apply), representing a more sophisticated cognitive processing (analyze) of an individual.

In the present study, the six categories of the cognitive dimension were divided into three higher-order categories; *perception*, *conception*, and *abstraction* (Figure 1), observed in the previous studies (e.g., Author, 2021). The perception level includes the intellectual demands at remembering and understanding levels where students perceive and comprehend what aspects of a scientific phenomenon through an in-class implementation developed based on an objective. At the perception level, an in-class implementation demands retrieving knowledge from long-term memory or constructing meaning from teachers' instructional messages from students. The conception level includes the intellectual demands at apply and analysis levels. Students must operate a procedure to a familiar task or distinguish relevant from irrelevant parts or necessary from unimportant parts of presented science contents in these levels. An implementation based on an objective at the conception level may demand students to decide how elements fit or function within a structure. The abstraction level incorporates the highest intellectual demands observed at evaluating and creating levels where in-class implementations allow students to transfer their understanding of science concepts and practices to unfamiliar contexts or different problems. An in-class task designed based on an objective at the abstraction level demands students to make judgments based on criteria and standards or put elements together to form a coherent or functional whole and reorganize elements into a new pattern or structure.

Sample analysis by translating theory into practice: In the previous studies (e.g., Elmas et al., 2020; Yaz & Kurnaz, 2020), the researchers adapted a methodology where an objective is scanned and matched with an action verb stated in the RBT to predict the objective's intellectual demand. This approach is theoretically valid and expectedly common; however, it is practically incomplete. The objectives guide a curriculum's principles as they are translated into practice through in-class implementations by teachers. Therefore, a mere action verb matching method will be oversimplified for a fine-grained systematic observation. Therefore, it was imperative in the present study to take a *hypothetical* stance to analyze the presumably created intellectual demands on the side of students through in-class implementations developed based on the curricular objectives. For this purpose, four researchers (two experts in the field of elementary/middle school science teaching and teacher education and two supporting investigators having expertise in the educational sciences) conducted the intellectual demand analysis by taking the possible usability of an objective in the sense of designing an in-class implementation into account.

First, all coders scanned an objective, then thought and imagined like a science teacher by frequently asking the

question, “*if I work with this objective which type(s) of in-class implementation(s) I design and share with my students?*” to themselves. This was functional for exploring the curricular objectives' intellectual demands in-depth. Next, four coders tried to ponder an objective's possible in-class usage(s) to make a more solid and practice-based estimation of its intellectual demand. Finally, a specific thinking-deciding diagram was developed and exemplified in Table 1 for the multifaceted intellectual demand analysis.

Three steps helped define an objective's intellectual demand using the *thinking-deciding diagram*: carefully scan an objective, estimate an intellectual demand the objective may possess, justify the estimation by proposing hypothetical instructional designs (Table 1). Nine hundred twenty-three objectives were analyzed by this method. Randomly selected 53 objectives from different curriculums were analyzed with the help of the thinking-deciding diagram by the full participation of the four coders. Technical (e.g., pedagogical, conceptual, etc.) issues were resolved through the constant comparisons and negotiations of different understandings on the triadic (scan-estimate-justify): considering an objective > instructional translation: identifying a presumptive in-class implementation by taking the objective's structural, semantic, and pedagogical content into account > determining an estimated intellectual demand of the objective. The remaining 870 objectives were analyzed independently by the researchers. Finally, 100 randomly selected thinking-deciding diagrams, including personally justified representations of the analyzed objectives, were reconsidered for predicting inter-coder reliability. At the outset, inter-coder reliability was 69%. Significantly, the coders had trouble assigning codes to the objectives pitched at the evaluate and create levels. Some contradictions were resolved by negotiating divergent meanings on the same objective (reliability coefficient: 81%).

Considering expert science teachers' reinterpretations: To foster the credibility of the analysis, 13 expert science teachers voluntarily checked the analyzed data by acting as external audits. Each science teacher controlled randomly selected 25 sample analyses completed by the primary coders. First, the teachers had information regarding the analysis sequence as the primary coders' thinking mechanism (thinking-deciding diagram) delivered to the teachers as diagrammatical representations (Table 1). They were then requested to determine whether the main coders' decisions are pedagogically plausible and pedagogically appropriate for authentic classroom settings. Second, the science teachers performed peer reviews by checking the data analysis and interpretations. The teachers played the devil's advocate role (Morse, 2015) and tried to make the primary coders honest. The science teachers jotted down explanations and rigorous questions on the analysis documents to press the primary coders to revise their initial interpretations. Therefore, the science teachers were able

Table 1 The thinking-deciding diagram as a chain: scan-estimate-justify

<i>Objective and estimated intellectual demand</i>	<i>Hypothetical instructional scene staging (justification for the estimation)</i>	<i>Potential cognitive pathways</i>
A student can classify light sources as natural and artificial.	Understand If I work with this objective, first, I request students to produce a list of light sources they have experienced. Then, through a brainstorming activity, I gather and pool the possible student-led examples of the light sources. Then, I invite students to categorize them. The students, of course, may propose different labels for their classifications. For example, suppose the intended classification as "natural <i>vs.</i> artificial" will not be proposed by students. In that case, I will propose this version of categorization, and then I request them to re-classify the light sources based on my proposal.	<ul style="list-style-type: none"> • Categorizing • Subsuming • Contrasting • Mapping • Matching
A student can associate exercise, breathing, and heart rate.	Apply I believe that this is an objective that may be coded at the application level. To justify, if one wants to make linkages between exercise, breath-taking, and heart rate, s/he has to make direct observations. First, we have to go out of the classroom. Imagine that we are on the 1 st floor. Then, I choose two students to carry out the directions I give them. The direction is that one of them runs to the 2 nd floor and returns with the same speed. Others may go to the 2 nd floor by walking. Other students are responsible for recording their observations. Alternatively, other students have to collect data from their friends whose different exercises influence their frequency of breath-taking and heart rate. After observations, students will be able to understand how these three different phenomena work together.	<ul style="list-style-type: none"> • Comparing • Contrasting • Illustrating • Categorizing • Concluding • Predicting • Executing • Implementing • Carrying out • Using
A student can determine the selection criteria for the thermal insulation materials used in buildings.	Evaluate This objective demands many things from students. First, students must know the primary difference between the two terms: heat, temperature. The students also have a knowledge base regarding heat transmission and the conditions in which heat transmission occurs. Second, a cumulative talk may propose relevant or irrelevant materials, such as a thermal insulator. Then, I demand students to differentiate the examples of the thermal insulator materials from the most effective one to the fewer ones. For this differentiation, they have to warrant their ideas. Therefore, they have to design experimental settings to test their initial hypothesis regarding the cost-effectiveness of thermal insulators. Then, they have to compare and contrast their experimental results for understanding, analyzing, criticizing, evaluating, and legitimating each other's interpretations. Then, collective thinking suggests the selection criteria for the thermal insulation materials used in buildings.	<ul style="list-style-type: none"> • Identifying • Categorizing • Concluding • Predicting • Comparing • Contrasting • Executing • Implementing • Carrying out • Using • Discriminating • Distinguishing • Selecting • Testing • Judging

to peruse both the process and the product of the account by constantly assessing their accuracy (Morse, 2015).

Quantifying and interpreting: After taking revision suggestions from the external audits, final decisions regarding the pedagogically-oriented intellectual demands of the curricular objectives were made. Finally, the systematic observations were quantified to have a more holistic portrayal of the distributions of the intellectual

demands across the years and science contents. This was needed to draw a generic picture of the distributions of the low, moderate, and high intellectually demanding curricular objectives.

3. RESULTS

As seen in Table 2, 132 curricular units' objectives were analyzed. On average, the curriculums seem to be

Table 2 Distribution of the units across three curriculums

Curriculum	Physics f(%)	Chemistry f(%)	Biology f(%)	Earth Sciences f(%)	Astrophysics f(%)	Total f(%)
2013	18(40.9)	8(18.18)	12(27.27)	2(4.54)	4(8.68)	44(100)
2017	22(47.82)	6(13.04)	12(26.08)	2(4.34)	4(8.72)	46(100)
2018	19(45.23)	6(14.28)	12(28.57)	2(4.76)	3(7.16)	42(100)
Total	59(44.69)	20(15.15)	36(27.27)	6(4.54)	11(8.35)	132(100)

Table 3 Distribution of the Objectives' Thematic Contents Across the Curriculums

Curriculum	Physics f(%)	Chemistry f(%)	Biology f(%)	Earth Sciences f(%)	Astrophysics f(%)	Total
2013	109	75	93	26	17	320
2017	122	62	87	9	30	310
2018	114	63	86	8	22	293
Total	345(34.06)	200(21.66)	266(28.8)	43(4.65)	69(10.82)	923

Table 4 The science concepts characterising the five content areas in the curriculums

Science content area	Characterizing topics as key concepts or keywords 2013 curriculum
Physics	Force and motion; effects of forces; measurement of force; force and energy; simple machines; Electric vehicles; simple electrical circuits; transmission of electricity; electrical energy; electricity in our lives Sound and light; lighting and sound technologies; spread of light and sound; reflection and refraction of light
Biology	Microscopic creatures Five senses; the journey to the world of the living; systems in our body; reproduction, growth, and development in living things Human and environment relations, living things, and their energy relationships
Chemistry	Particulate state of matter; substances and energy (heat, energy, etc.) Substances and their general features; state change of substances; states of matter and heat
Earth sciences	The earth's crust and the movements of our earth; earthquakes The motion of the earth around its axis; weather events
Astrophysics	Planet Earth; interactions between sun, earth, and moon Solar system and beyond

dominated by the *physics-based* units in addition to the *biology-based* ones. On average, more than 40% of the units were in the curriculum's physics concepts.

There are fewer chemistry-based units (15.15%) in the curriculum compared to the physics-based or biology-based units (27.27%). On average, more than one-fourth of the units across the curriculums were for the biology concepts. On the other hand, there was less place for the *earth sciences* (4.54%) and *astrophysics* (8.35%) units. Even though three changes were actualized to improve the science curriculums, the distribution of science contents or conceptual structure of the curriculums were strictly protected over the years.

Similarly, the physics-based objectives seem to be included in the curriculums more pervasively than other content areas. More than one-third of the 923 objectives were explicitly related to the physics concepts. Secondly, the biology-based objectives seem to dominate the curricular objectives' distribution. Even though fewer units (Table 2, 15.15%) were for the chemistry-based concepts on average, more chemistry-based objectives were in the curriculums (Table 3, 21.66%). The objectives devoted to the earth sciences concepts were under 5% on average across the curriculums. Only one-tenth of the objectives in the curriculums were for the astrophysics concepts (Table 3).

Five content areas were characterized by different concepts across the curriculums presented in Table 4. The three curriculums showed a similar thematic sequence regarding the extracted five content areas. Some specific concepts were strictly rehearsed across the curriculums. For example, three higher-order themes were for the physics content area: *force*, *electricity*, *light*, *sound*, and *energy*. In the physics content area, especially *force* and *electricity* concepts and sub-concepts, nature's mechanics (Table 4) dominated the objectives' thematic structure.

Three themes were for the biology content area: *microbiological perspective*, *macro biological perspective*, and *ecology*. Most biology-related concepts in the curriculums appeared, prompting students to comprehend part-whole relations regarding biological systems. There is a similar conceptual sequence for the chemistry-based concepts around three segments: *micro world*, *macro world*, and *chemistry in daily life*. Microworld includes an explanatory dimension where students should think and talk about invisible segments of substances. The macro world defines a descriptive-functional dimension, and the concepts are only experienced or observed at the visible and tangible levels. The macro dimension requires in-depth articulations,

Table 4 The science concepts characterising the five content areas in the curriculums (*Continued*)

Science content area	Characterizing topics as key concepts or keywords
2017 curriculum	
Physics	Characteristics of forces; force and motion; force and energy; effects of forces; measurement of force and friction; pressure; simple machines Electric charges and electric energy; transmission of electricity; electric vehicles; simple electrical circuits Lights and sounds around us; lighting and sound technologies; spread of light; sound and its features; interaction of light with matter
Biology	Cell division; DNA and genetic codes Five senses; the journey to the world of the living; foods and biological systems; systems in our body; systems in our body and their health; reproduction, growth, and development in living things Human and environment; energy transformations and environmental science
Chemistry	Substances and energy (heat, energy, etc.); pure substances and mixtures Substances and their general features; state change of substances Substances and industry
Earth sciences	The earth's crust and the movements of our earth Seasons and climate
Astrophysics	Planet Earth; sun, earth, and moon Solar system and eclipses; solar system and its beyond
2018 curriculum	
Physics	Force and motion; force and energy; effects of forces; measurement of force and friction; pressure; simple machines Electricity, electric vehicles, simple electrical circuits, electrical circuit components, the transmission of electricity; electric charges, and electric energy Lighting and sound technologies; spread of light; sound and its features; interaction of light with matter
Biology	DNA and genetic codes Cell and its division; foods and biological systems, systems in our body, five senses, the health of systems in our body; reproduction, growth, and development in living things Human and environment relations, energy transformations and environmental science
Chemistry	Substances and energy (heat, energy, etc.), pure substances and mixtures Substances and their general features; state change of substances Substances and industry
Earth sciences	The earth's crust and the movements of our earth Seasons and climate
Astrophysics	Planet Earth; interactions between sun, earth, and moon Solar system and eclipses; solar system and its beyond

explications, or causations of concepts at the micro-level. Earth sciences content area incorporated two thematic parts: a *formation* mainly related to nature's materialistic history and *earth's cycles* as laws of nature. Lastly, the astrophysics content area also included two thematic flows as *terrestrial* and *extra-terrestrial systems*.

3.1. Horizontal interpretations

The 2013 curriculum. Table 5 shows the distributions of the objectives' intellectual demands placed in different science content areas and curriculums. For the 2013 curriculum, about 30% of the physics and biology contents objectives stayed at the *perception level* (remember, understand). More objectives at the level of perception

were for the chemistry topics (37.3%) compared to the physics-based or biology-based contents. On the other hand, the objectives' intellectual demands were dramatically pitched at the perception level for the earth sciences and astrophysics contents. Most of the objectives were evaluated at the *conception level* (apply, analyze). For instance, more than six out of 10 physics objectives were at the conception level. However, there was a sharp decrease in the objectives evaluated at the *abstraction level* (evaluate, create) in the 2013 curriculum. Less than one-tenth of the objectives of the physics, chemistry, and astrophysics content areas were at the abstraction level. However, especially for the biology-based contents, more objectives

Table 5 Vertical and horizontal frequencies of the objectives regarding year, content area, and intellectual demand

Curriculum	Cognitive demand	Physics f(%)	Chemistry f(%)	Biology f(%)	Earth Sciences f(%)	Astrophysics f(%)
2013	Perception	30(28.3)	28(37.3)	29(31.18)	13(50)	8(47.05)
	Conception	69(63.3)	40(53.3)	43(46.23)	8(30.76)	8(47.05)
	Abstraction	10(8.4)	7(9.4)	21(22.59)	5(19.27)	1(5.9)
	Total	109(100)	75(100)	93(100)	26(100)	17(100)
2017	Cognitive demand	Physics	Chemistry	Biology	Earth Sciences	Astrophysics
	Perception	41(33.6)	23(37.09)	33(37.93)	7(77.78)	20(66.66)
	Conception	58(47.54)	25(40.32)	34(39.08)	1(11.11)	9(30)
	Abstraction	23(18.86)	14(22.59)	20(22.99)	1(11.11)	1(3.34)
2018	Total	122(100)	62(100)	87(100)	9(100)	30(100)
	Cognitive demand	Physics	Chemistry	Biology	Earth Sciences	Astrophysics
	Perception	44(38.59)	24(38.09)	37(43.02)	7(87.5)	15(68.18)
	Conception	58(50.87)	28(44.44)	32(37.2)	1(12.5)	6(27.27)
2018	Abstraction	12(10.54)	11(17.51)	17(19.78)	0(0)	1(4.55)
	Total	114(100)	63(100)	86(100)	8(100)	22(100)

were found at the abstraction level (22.59%) like the earth sciences objectives (19.27%).

The 2017 curriculum: More homogeneous distributions of increasing and decreasing intellectual demands across the content areas were valid in the 2017 curriculum. For the physics, chemistry, and biology content areas, more than 30% of all the objectives were in the perception zone (Table 5). However, a substantial amount of the objectives in the earth sciences and astrophysics contents were at the perception zone. In terms of the conception zone, the chemistry and biology contents had a very similar tendency of the objectives' intellectual demand; however, nearly one out of two objectives in the physics contents were at the conception level. The objectives of the astrophysics contents were more frequently observed than the earth sciences contents' objectives in terms of conception zone. Regarding the abstraction zone, the objectives in the physics, chemistry, and biology contents were around 20%. This was slightly frequent than the objectives placed in the earth sciences contents and significantly frequent than the astrophysics contents.

The 2018 curriculum: On average, 40% of the objectives stayed at the perception level in the physics, biology, and chemistry contents. For the earth sciences and astrophysics contents, the objectives stayed at the perception level dominated the curriculum (Table 5). There was a decremental tendency of the objectives pitched at the conception level from the physics (50.87%) to chemistry (44.44%) to biology (37.2%) contents. There were sharp decreases in the earth sciences (12.5%) and astrophysics (27.27%) contents from the objectives stayed at the perception level to the objectives observed at the conception level. The objectives observed in the chemistry and biology contents were significantly higher than the

physics-related objectives observed at the abstraction level (Table 5).

3.2. Vertical interpretations

Physics content areas: Across the curriculums, there was a consistent increase from the former (2013) to the latter curriculums (2017, 2018) regarding the objectives observed at the perception level for this content area (Table 5). There was a dramatic decrease from the 2013 curriculum to the 2017 curriculum regarding the conception level. The 2018 curriculum incorporated similar objectives in the physics content areas compared to the 2017 curriculum. Regarding the abstraction level, there was an increase from the 2013 curriculum to the 2017 curriculum; however, in the 2018 curriculum, there was a decrease in this level of intellectual demand for the physics contents.

Chemistry content areas: A consistency (on average, 40%) in the objectives stayed at the perception level across the curriculums for the chemistry-related topics (Table 5). There was an apparent decrease from the 2013 curriculum to the 2017 and the 2018 curriculum regarding the conception level. Regarding the objectives observed at the abstraction level, there was a significant increase from the 2013 curriculum to the 2017 curriculum. A slight decrease was also observed from the 2017 curriculum to the 2018 curriculum for the objectives of the chemistry topics.

Biology content areas: Regarding the perception level, there was a constant increase from 2013 to the 2017 curriculum, but the increase from 2013 to the 2018 curriculum was more significant than the difference between the 2013 and 2017 curriculums (Table 5). There was a consistent decrease from the former to the latter curriculums regarding the conception level. However, regarding the abstraction level, there was a consistency in the amounts of the objectives of the biology topics.

Therefore, the objectives observed at the perception level were replaced with the objectives observed at the conception level from 2013 to the 2018 curriculum in the sense of biology topics.

Earth sciences content areas: There was a sharp increase in the objectives found at the perception level in this content area from 2013 to the 2018 curriculum (Table 5). However, there was a more dramatic decrease from the 2013 curriculum to the 2018 curriculum regarding the conception level. This implies that the objectives observed at the perception and conception level were replaced, favoring the perception level for the earth sciences topics. Regarding the abstraction level, even though there was a slight decremental tendency from 2013 to the 2017 curriculum, a very sharp decrease was also observed from the 2013 to 2018 curriculum about the objectives observed at the abstraction level (Table 5).

Astrophysics content areas: From the 2013 curriculum to the 2017 curriculum, there was a tremendous increase in the objectives coded at the perception level for this content area. However, there was no substantial change between the 2017 and 2018 curriculums regarding the objectives observed at the perception level (Table 5). Similarly, regarding the conception level, there was a dramatic decrease from 2013 to the 2017 curriculum; however, the 2017 and 2018 curriculums included relative amounts of the objectives evaluated at the conception level. Finally, there was a dramatic change for the objectives at the abstraction level from 2013 to the 2018 curriculum (Table 5).

The examined objectives in the three curriculums were weighted regarding their presumptive intellectual capacity represented as Figure 2 for generating a holistic portrayal. As inferred from the cumulated averages, there was a heterogeneous distribution of the objectives regarding their intellectual demands across the curriculums. In addition, the curricular content areas were dominated mainly by the objectives observed at the perception or conception zones

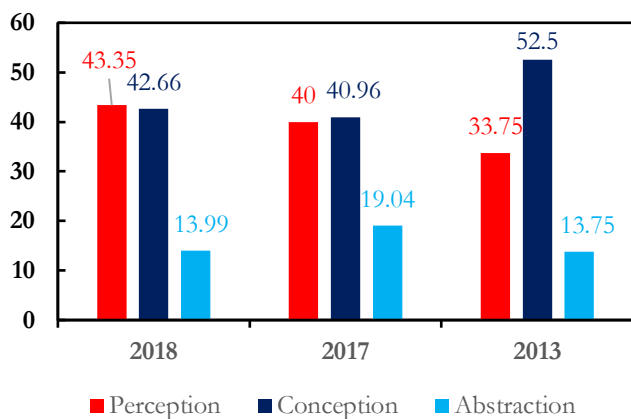


Figure 2 The general picture of the objectives' intellectual demands across the curriculums

(Figure 2, more than 80% of all objectives). As a result, fewer curricular objectives were observed in the abstraction zone in the curriculums.

In the 2013 curriculum, more than 85% of all the objectives were at either perception or conception zone. The 2013 curriculum seemed to be dominated by the applying or analyzing level (conception zone). However, the objectives observed at the abstraction zone were significantly rare compared to the perception or conception zone for the 2013 curriculum. The 2017 and 2018 curriculums, on the other hand, appeared to have a higher intellectual capacity regarding the objectives observed at the abstraction zone compared to the 2013 curriculum. Thus, the 2018 and 2017 curriculums seemed to have a very similar pattern of intellectual capacity. However, even though there was an increase in the abstraction zone in the latest curriculums compared to the 2013 curriculum, there was also a dramatic incremental tendency in the perception zone in the 2017 and 2018 curriculum compared to the 2013 curriculum. In conclusion, the overall intellectual capacity of the curriculums seemed to be stable, particularly from the 2017 curriculum to the 2018 curriculum that was seemed to be created by simply cloning the 2017 curriculum.

4. DISCUSSION

In the current student, a specific question is addressed, such as describing the embedded intellectual capacity of the science curricula. It was found that the science curriculums examined in the present study mainly were incorporated physics-related (*main themes:* force, electricity, and light, sound, and energy) and biology-related topics (*main themes:* microbiological perspective, macro biological perspective, and ecology) in addition to the chemistry-related topics (*main themes:* micro world, macro world, and chemistry in daily life). There is less place for the topics related to astrophysics and earth sciences. This infers that although three modifications were actualized to enrich the intended science curriculums, the distribution of the conceptual coverage or emphasis seemed to be strictly protected over the years. The static nature of the curriculums may signal that the curriculum developers did not intend to boost the easiness, meaningfulness, and quality of learning in school subjects that are possible through the wise and emergent modifications of coverage or focus of a curriculum (Fortus & Krajcik, 2012).

It has known that students may have misconceptions, especially regarding the physics-related topics (e.g., *I have consumed my energy today*) covered by the investigated curriculums (Duit & Treagust, 2012; Vosniadou, 2012). There are conceptual differences between students' existing mental schemes and physics topics teachers try to introduce (Vosniadou, 2012). Studies showed that, especially for the context of physics-related topics, conceptual, epistemological, and ontological distances

between the social language of school science and students' every day or primarily incomplete/invalid social languages might emerge. When this distance is the case, a version of *learning demand* (Mortimer & Scott, 2003) that is considerably related to the intellectual demand occurs. When there is higher learning demand on the side of students, science teachers have to create high intellectually demanding in-class tasks to invite students to adopt new ways of seeing and understanding science phenomena. Once a teaching sequence displays a higher learning demand, it would guide science teachers to take an internally influential role in pressing students for an intentional conceptual change (Duit & Treagust, 2012; Vosniadou, 2012). However, science curriculums must permit teachers to generate high cognitively demanding tasks (Luke, 2010; Tekkumru-Kisa et al., 2019; Wan & Lee, 2020) to persuade students to think and talk in new ways as social languages of school science.

As seen in the present study, physics-related objectives were mainly pitched at the low intellectual demand levels across the curriculums. This was also valid for the biology-related and chemistry-related objectives that dominated the curriculums. These results follow the recently reported nation-based studies (Aktan, 2019; Aydın et al., 2019; Cangüven et al., 2017; Zorluoğlu et al., 2020). This implies that the curricular objectives had less potentiality in activating a version of higher-order learning demand that is possibly created on the side of students by teacher-led in-class tasks structured based on the objectives. As presented, a more *heterogeneous* distribution of the curricular objectives regarding the intellectual demand was detected. Regardless of the year and science content area variables (Table 5), the intellectual demands embedded in the curricular objectives primarily accumulated in the *perception* (remember, understand) and *conception zone* (apply, analyze) (Figure 2). In the *abstraction zone* (evaluate, create), there was a sharp decrease across the curriculums (Figure 2) and content areas (Table 5) compared to the less intellectually demanding objectives observed at the perception or conception zone. The curriculums under examination seemed to let the teachers design and implement high intellectually demanding tasks to teach science knowledge and epistemic practices, however, to a certain extent. The sharp decreases in the number of objectives observed in the abstraction zone may hinder teachers from generating in-class teaching environments where students can transfer acquired knowledge and practices to diverse external contexts.

When the thematic emphases of the curricular objectives are considered, especially in the biology-related and chemistry-related topics, a zigzag or back-and-forth sequence was valid. These science content areas seemed to be structured based on the whole-part relationships as the curricular objectives appeared, prompting science teachers to design instructional settings where students connect the

micro-worlds and the macro worlds of, for instance, living things or substances. Johnstone (1991; 1993; 2000) proposed two dimensions of teaching and learning chemistry-related concepts: macro and micro, observed in the examined curricular objectives. The macro dimension implies that concepts (five senses, substances, and their general features) are placed in students' existing mental schemes as workable models. The macro dimension is inherently visible and tangible in students' experiential imaginations. The micro dimension includes more analytically-oriented worlds of science phenomena, including articulations, explications, or causations of concepts under consideration (Gilbert & Treagust, 2009). The changes in the micro dimension determine the changes in a related macro dimension as a part-whole relationship sequence.

Students must establish reality as an interactional mixture of micro and macro dimensions. For doing science, especially in the chemistry-related concepts (e.g., solutions, atoms, molecules), students may hold cognitive difficulties in describing and materializing them (Gilbert & Treagust 2009). Some chemistry-related concepts (e.g., atoms, molecules, intermolecular forces) characterizing the micro dimension may also substantially challenge teachers to teach them. However, these concepts may present more significant teaching opportunities for science teachers by designing higher intellectually demanding tasks (Wan & Lee, 2020) and attaching micro and macro dimensions. Students feel more comfortable comprehending a macro dimension of a science concept that is more concrete or simpler than the micro dimension of the concept. This means that more intellectual demand will occur when science teachers design a teaching task based on the objective indicating a micro dimension of a concept compared to the macro dimension of the concept. Students may have difficulties elucidating the macro dimension changes by referring to the micro dimension (Gilbert & Treagust, 2009).

Drinking a cup of sugared tea and knowing that its taste is due to sugar is simply about students' personal experiences and expressed through a low intellectually demanding objective structured in the macro dimension observed in the present study. However, understanding the interactions in the micro dimension will be complicated for students to imagine how water and sugar molecules behave differently when they are mixed. A high intellectually demanding objective expresses this. Herein, it should be in question whether science teachers can use the mentioned instructional opportunity. To achieve this, first, science teachers should have a *conscious awareness* (e.g., the curricular objectives stated in micro and macro dimensions may incorporate lower and higher degrees of intellectual demand) regarding micro and macro dimensions observed in the curricular topics. Therefore, the present study's outcomes can guide teachers in reading and knowing the

curricular objectives in a new way by attributing the interaction between the micro and macro dimensions. Secondly, as detected, the distribution of the curricular objectives was dramatically heterogeneous. Low (perception: remember, understand) and moderate (conception: apply, analyze) intellectually demanding curricular objectives dominated the curriculums across the science content areas compared to the highest intellectually demanding ones (abstraction: evaluate, create). Thus, it is still a problem since even though the content coverage has flowed as a way in which students may perform inductive/deductive thinking by working with micro/macro dimensions together, the heterogeneous distribution of the intellectual demand may inhibit this highly recommended instructional sequence as a journey between the visible and invisible parts of natural phenomena.

The tendencies observed in the curricular objectives' intellectual capacity also show that *intellectual rigor* is not trivial (Wan & Lee, 2020). The intended curriculums explored in the present study signal the apparent lack of intellectually rich and discrepant science content areas. Therefore, the present study is an invitation to reconsider the content standards or tendencies and the quality of those standards (Schmidt, Wang, & McKnight, 2005). The Turkish curriculums may contain extensive coverage of science topics. However, another significant matter is whether an instructional opportunity embedded in a curricular objective can guide science teachers to design and conduct an intellectually demanding task. This issue is also visible in the other countries' science curriculums; for instance, it was doubtful whether Australian science curriculums would up the intellectual capacity in primary classrooms (Luke, 2010). Schmidt et al. (2001) reported that the American science curriculums included shallow intellectual capacity in the presence of pervasive coverage of topics, resulting in poor academic performance. This situation is not different in the Canadian science curriculums in increasing students' scientific literacy with the low intellectually demanding curricular objectives (Fitzpatrick & Schulz, 2015). East-Asian countries have had the same problem (Wei & Ou, 2019) to materialize a more demanding science curriculum by inviting science teachers to foster students' cognitive capacity via in-class tasks where intellectual rigor is centralized. In the Turkish science curriculums, Yaz and Kurnaz (2020) concluded that a sharp decrease was visible regarding their intellectual-instructional potentiality and capacity. Yaz and Kurnaz (2020) drawn attention to the point that one of the significant indicators of poor student performance in the international assessments (e.g., PISA (Programme for International Student Assessment) and TIMSS (Trends in International Mathematics and Science Study)) is the intended science curriculums including less knowledge building capacity showed evidently in the present study.

CONCLUSION

This study concluded that Turkey's last three science curricula implemented might not give teachers some crucial instructional opportunities to handle high cognitively demanding in-class implementations by taking different science-related concepts into account.

Based on the present study results, for the Turkish curriculum development context, it may be time to quit the top-down pressures, adapted for a very long time, by deliberately welcoming in-service science teachers as curriculum designers. Teachers critically interact with curriculum resources such as curricular objectives (Beyer & Davis, 2012a; 2012b). Carlgren (1999) indicated that teachers "actively construct, invents, develops, and designs the practice of schooling" (p. 50). Therefore, teachers are not mere *doers* of the curriculum; they are the curriculum designers to generate authentic learning opportunities for students (Remillard, 1999). Therefore, it will be a strategic tactic for Turkish curriculum developers to acknowledge science teachers as translators of curricular contents into teachable entities expected to be intellectually demanding to form the future's minds. For instance, in the present study, the science teachers were seen as external audits or peer reviewers identifying the intellectual demands embedded in the curricular objectives. In the informal conversations, the supporting teachers declared that they had never *read* the science curriculums in this way (e.g., analyzing intellectual demand of an objective) introduced to them via the present study.

One of the limitations of the current study is that science teachers' in-class implementations are not systematically observed. This would be vital to determine whether a science curriculum would be used in an intended manner or precisely as defined by science teachers. To be clear, it is more about a science teacher's pedagogical capacity as s/he may use a low cognitively demanding objective to design and implement a high demanding instructional scene staging. On the other hand, a science teacher may underestimate a curricular objective's intellectual capacity and plan and conduct a low intellectually demanding instructional sequence based on the objective even though it pitches at the analyze, evaluate, or create levels.

Therefore, further research must consider the reciprocal interactions between the presumable intellectual capacity of a science curriculum and instructional sequence building capacity and capability of a science teacher since science teachers are well accepted as the translators of the curricular content. Moreover, in the current study, only the cognitive dimension of the RBT was used to re-read the intellectual capacity of the science curricula. Therefore, a further analysis based on the knowledge dimension of the RBT would also be elucidatory in terms of giving some specific answers to the research questions addressed in the present study.

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