Dynamic Equilibrium In Science: Comparison Between The Israeli And United States Frameworks And Representations In The Standards And Textbooks

Tamara Dawud[1], Sebahat Gok[2], Sharona T. Levy[1] and Uri Wilensky[2]
[1]University of Haifa, Israel
[2]Northwestern University, USA

The study examines how Dynamic Equilibrium (DE) is represented in science national standards and textbooks for high-school biology, chemistry, and physics in the US and Israel. DE, a crucial concept in understanding dynamic systems, is inconsistently represented across educational materials and students encounter difficulties learning about DE. Analysing 17 textbooks and national standards, the research combines quantitative and qualitative content analysis to assess the frequency and nature of presentation of DE-related phenomena. The study identifies 256 DE-related phenomena, comprising 14% of all phenomena that are studied in science. The primary systems approach used is System Dynamics, which focuses on stocks and rates of flow at one description level. The main representational format is verbal, and computational models are scarcely used. Differences across disciplines and between countries were found. These findings emphasize the need for powerful representations of DE to enhance students' understanding of dynamic systems and improve science education.

Keywords: Dynamic equilibrium; Science education; Systems thinking; Textbook analysis; Scientific representations; Cross-national comparison.

Introduction, Theoretical Perspectives, And Research Goal

This paper examines the concept of Dynamic Equilibrium (DE) in the US and Israeli high school science standards and textbooks, focusing on its role as a structuring concept across the natural sciences. DE is fundamental for understanding patterns in dynamic systems, describing systems that maintain stability through continuous balancing influences (Biology Dictionary, n.d.), such as homeostasis in biology, ecological systems, and chemical equilibrium. Despite its significance, DE remains a challenging concept for students, with difficulties arising from the contradiction between the system's stable appearance and the dynamic processes that maintain it (Sarıçayır et al., 2006). Students often struggle to understand stability as a dynamic process rather than static constancy, as seen in alternative concepts about chemical equilibrium (Nakhleh, 1992; Özmen, 2008) and homeostasis (Zion & Klein, 2015).

DE is analysed through systems frameworks like System Dynamics (SD; Forrester, 1961), Structure-Behavior-Function (SBF; Hmelo-Silver & Green Pfeffer, 2004), and Agent-Based Modeling (ABM; Wilensky & Rand, 2015). These frameworks focus on understanding system behavior and emergent patterns, helping students grasp the dynamic and parallel nature of equilibrium in complex systems. DE plays a key role in science education, particularly in the NGSS standards, which include Stability and Change as a crosscutting concept related to DE (NGSS, 2013). Proper instruction on DE fosters systems thinking and enhances students' understanding of complex processes across multiple levels of representation. The high school curricula in the US and Israel differ in structure. In the US, students are exposed to a wide range of subjects, with opportunities for specialization through programs like AP courses. In Israel, students specialize in one or two subjects, limiting exposure to other fields. Assessments also vary: in the US, GPA and standardized tests like the SAT or ACT are used, while in Israel, the Matriculation (Bagrut) exams focus on the chosen specialization subjects.

This study is part of a larger international project, which aims to develop better representations of DE to address the identified learning challenges. By comparing national standards and textbooks from both countries, we seek to understand how DE is structured, conceptualized, and conveyed within different educational contexts. The research excludes supplementary or external teaching materials. This research aims to compare how DE is represented in the science curricula and textbooks of the US and Israel and identify the DE-related phenomena and their representational formats. Additionally, it examines how different system frameworks are applied across subjects and countries. Through a cross-national analysis, this study seeks to uncover both expected and unexpected instances of DE in science education, with an emphasis on improving representations to enhance student comprehension of dynamic systems.

Methodology

The study analysed the content and representations related to DE in the main science textbooks and national standards of Israel and the US (Israel Ministry of Education, 2024; US NGSS, 2013; US National Research Council, 2012). A qualitative mixed-methods content analysis (Krippendorff, 2019; Schreier, 2012) categorized DE-related phenomena into seven representational formats: verbal, equation-based, graphical, tabular, photographic, illustrative, diagrams, and computational (e.g., simulations). “Phenomenon” is defined in the analysis as an object-involving occurrence, where an object (or system) undergoes a process, an event, or a state (Kaiser & Krickel, 2017). The analysis focused on the frequency of DE phenomena and the system frameworks used to describe them. This study does not encompass the entire student learning environment, acknowledging that lab work and external resources also play a role in student engagement with DE concepts.

Findings

Content Of The Curricula

An overview of the high school science curricula in the US and Israel was conducted to identify overlap and facilitate comparison. The standards and textbooks’ topics were subdivided into content-based groups, aligning them as categories. The number of phenomena in each discipline in both countries was counted (see Figure 1).

In biology, the curricula in both countries cover similar topics, with some differences in emphasis. Key topics include cellular biology, human and animal biology, and ecological systems. Both countries address cell structure, organelle functions, and processes like respiration and protein synthesis. The US emphasizes substance transport, while Israel teaches fermentation and meiosis in cell division. Both countries teach human and animal biology, including body systems, physiology, and genetics. In ecology, both curricula cover ecosystems and human impact, with the US focusing more on energy flow and succession, while Israel emphasizes human impact and ecological organization. The primary difference is that the US includes evolution and biodiversity, topics absent in Israel.

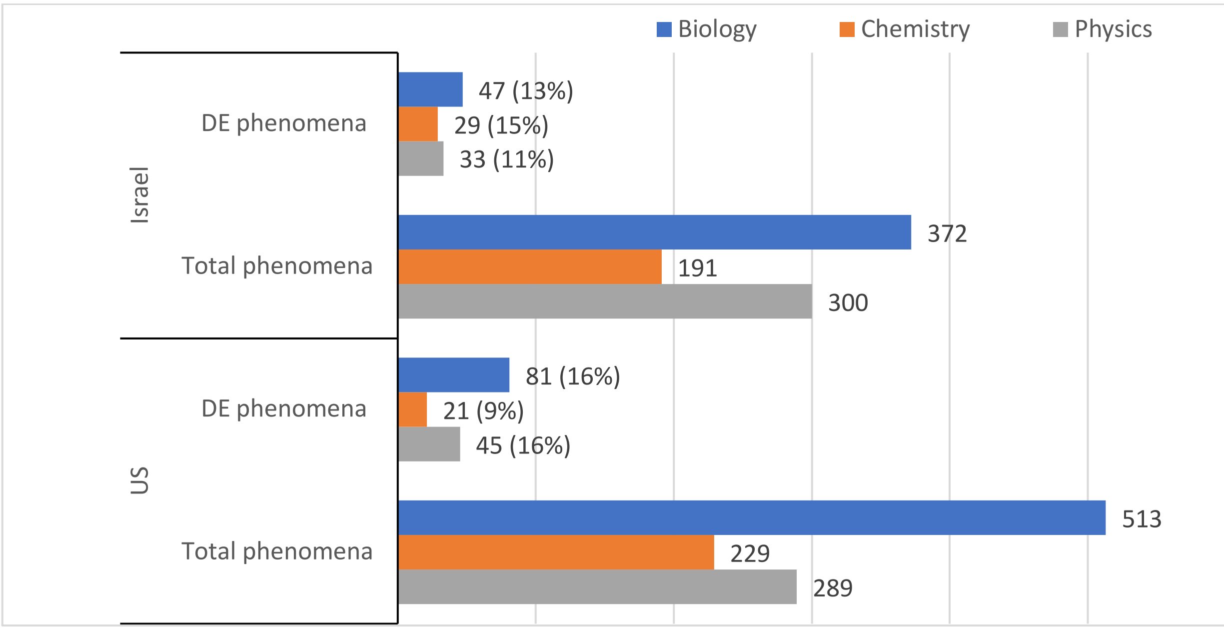
In chemistry, the curricula in both countries align closely, focusing on similar principles, though differences arise in depth or emphasis. Topics include atomic structure, chemical bonds, energy changes, food chemistry, and chemical equilibrium. Both countries address oxidation-reduction, chemical reactions, and factors affecting equilibrium. The main differences are in the level of detail or emphasis in specific areas.

In physics, both curricula cover forces and motion, energy, electricity and magnetism, and radiation and matter, with some differences. For forces and motion, Israel emphasizes Newton's laws and momentum conservation, while the US focuses on force-mass-acceleration relationships and real-world applications like collisions. Both curricula cover energy, with Israel focusing on mechanical energy and the US highlighting energy transfer and work-energy principles. In electricity and magnetism, both teach electric fields and Ohm's law, with Israel covering electromagnetic induction and the US emphasizing applications like circuits and power generation. In radiation and matter, both curricula address atomic and nuclear physics, with Israel focusing on atomic structure and quantum phenomena, while the US connects these topics to real-world applications like medical technologies. The differences lie in Israel's focus on foundational concepts and the US's emphasis on applications.

Identification And Counting Of DE-Related Phenomena

We identified phenomena embodying the principle of DE in the standards and textbooks, including those not explicitly defined as DE phenomena. The total number of phenomena and DE-related phenomena are shown by discipline (biology, chemistry, physics) for both countries (see Figure 1).

Figure 1. Frequency of All Phenomena and DE-Related Phenomena Across Disciplines (Biology, Chemistry, Physics) in the US and Israel Standards and Textbooks.

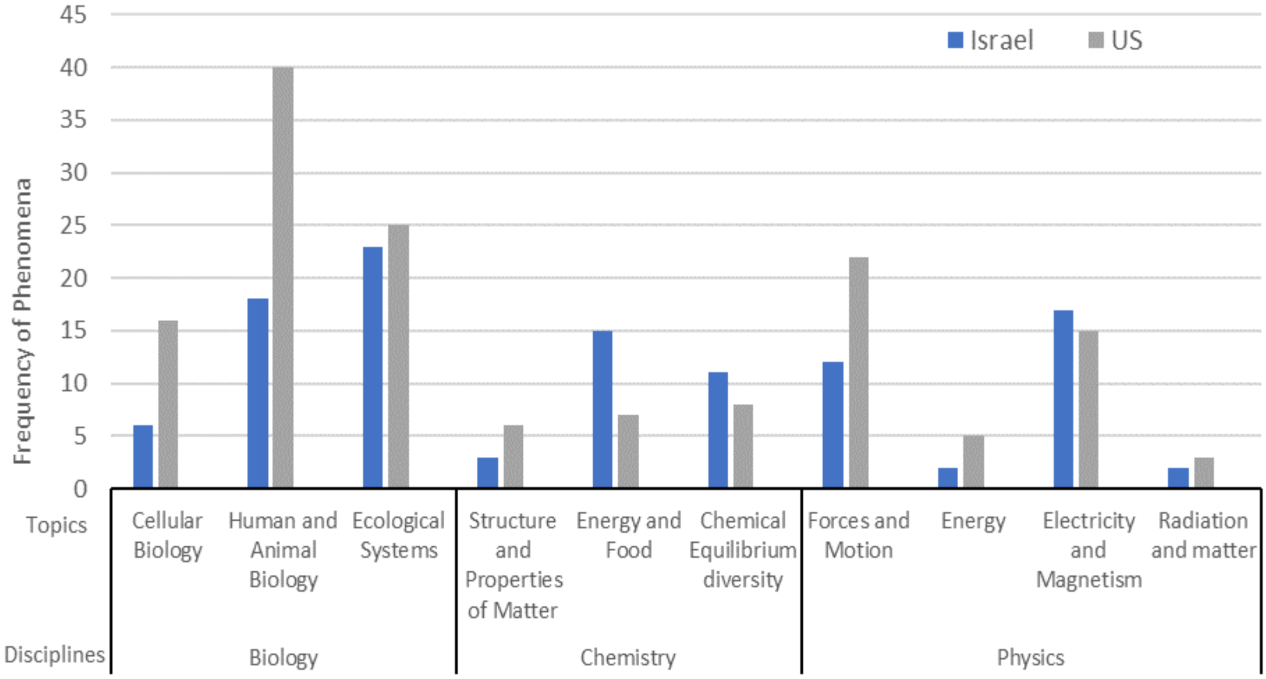


Overall, there are 256 DE-related phenomena across the three disciplines. In the US, 147 DE-related phenomena were identified, making up 14% of all phenomena. In Israel, 109 DE-related phenomena were found, representing 13% of the total. DE-related phenomena are most common in biology, followed by physics, then chemistry. In physics and chemistry, the total number of phenomena is similar between the two countries, but the US has a higher overall number of phenomena. The proportion of DE-related phenomena is greater in the US than in Israel for biology and physics, while in chemistry, Israel has a higher percentage of DE-related phenomena.

Distribution Of DE-Related Phenomena

We identified DE-related phenomena in the standards and textbooks, including those not explicitly defined as DE phenomena. Figure 2 shows the distribution by discipline and topic.The US and Israeli curricula align on half of the ten topics. However, the US includes more DE-related phenomena in forces and motion (physics) and cellular and animal biology (biology), while Israel emphasizes energy and food and chemical equilibrium (chemistry). Of the 256 phenomena examined, 11 describe chemical equilibrium, 27 address homeostasis, and 13 involve ecological systems, all traditionally linked to DE. Notably, 205 phenomena, representing 80% of DE-related phenomena and 11% of all described phenomena, depict DE processes in topics not previously defined as DE-related.

Figure 2. Distribution of DE-Related Phenomena Across Disciplines (Biology, Chemistry, Physics) and Topics in the US and Israel High School Textbooks.



DE Representations' Format

In future research, we will develop and explore new computational representations for DE. The study examined the prevalence of various representation formats in DE-related phenomena within US and Israeli textbooks, categorized as verbal, mathematical, graphical, tabular, photographic, illustrative, diagrammatic, and computational models (see Table 1).

Table 1. Format of Representations of DE-related Phenomena According to Textbooks in the US and Israel.

			Representation Format (% of N)							
Discipline	**Country**	**Phenomena (N)**	Model	Diagram	Illustration	Photograph	Table	Graph	Equations	Verbal
Biology	UA	81	18	26	48	13	1	5	6	100
	Israel	47	0	42	38	27	22	27	9	100
Chemistry	US	21	0	25	63	17	8	25	79	100
	Israel	29	3	0	11	0	24	29	34	100
Physics	US	45	0	20	76	20	4	31	73	100
	Israel	33	0	8	82	10	8	13	62	100

The study examined the prevalence of various representational formats in DE-related phenomena within US and Israeli textbooks, categorized as verbal, mathematical, graphical, tabular, photographic, illustrative, diagrammatic, and computational models. Overall, the frequency of representation formats follows the order: verbal > illustration > mathematical > diagram > graph

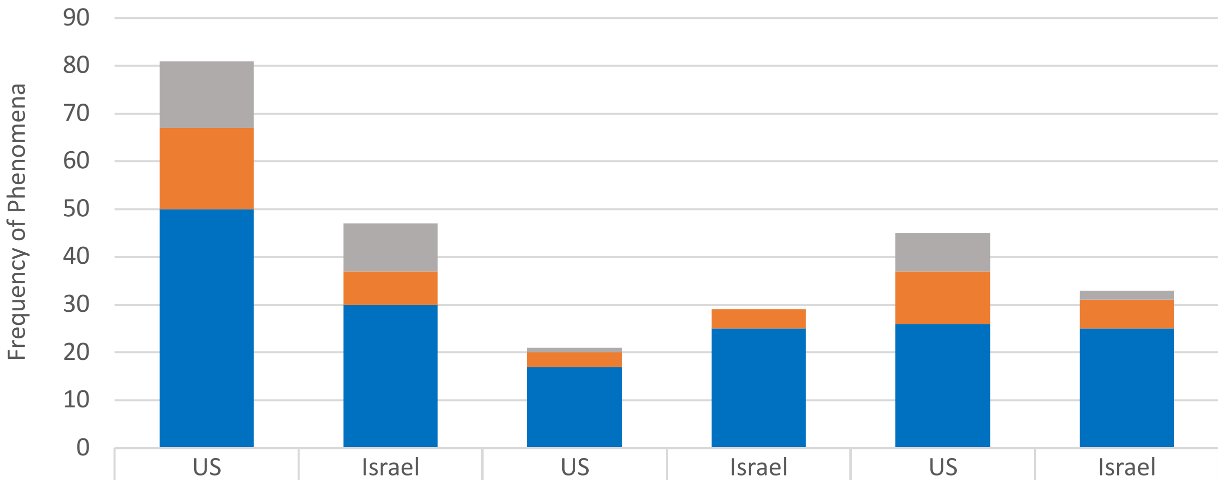
> table > computational model. Israeli biology textbooks feature six representation types in at least 20% of sections, compared to three in US textbooks. In physics, US textbooks include six types at this level, versus three in Israel.

Representations' Systems Framework

We analysed textbook explanations by systems frameworks: System Dynamics (SD), Structure-Behavior-Function (SBF), and Agent-Based Modeling (ABM). Explanations were coded using seven dimensions: behaviors and properties of components (ABM, SBF), randomness (ABM), interactions between components (ABM, SBF), functions (SBF), heterogeneity of entities (SBF), and stocks and rates (SD). These dimensions helped identify the frameworks in DE explanations (Figure 3).

SD dominates across disciplines with 173 phenomena, while ABM appears in 48 and SBF in 35. In biology, SD is most common, with ABM and SBF appearing less frequently. Chemistry is dominated by SD, with minimal ABM and almost no SBF, especially in Israel. In physics, SD is again prevalent, with ABM more frequent than SBF.

Figure 3. Frequency of System Frameworks (SD, ABM, SBF) Representing DE-related Phenomena Across Disciplines (Biology, Chemistry, Physics) and Countries.



	Biology		Chemistry		Physics	
	US	Israel	US	Israel	US	Israel
SBF	14	10	1	0	8	2
ABM	17	7	3	4	11	6
SD	50	30	17	25	26	25

Discussion

The research is part of an international project focused on developing representations for DE, a central idea in science that describes how stable patterns form in dynamic systems. It examines the representation of DE in high school science curricula and textbooks in the US and Israel, comparing the content across biology, chemistry, and physics. Key objectives include exploring how DE phenomena are presented and represented through various tools such as graphs, illustrations, and computational models, while analysing differences across disciplines and countries. The study also investigates the use of system approaches like System Dynamics (SD), Agent-Based Modeling (ABM), and Structure-Behavior-Function (SBF) in explaining DE phenomena. Findings reveal that DE-related phenomena make up approximately 14% of the curricula, though many are not explicitly defined as DE-related. Significant differences in the curricula were noted, such as the emphasis on evolution in US biology education versus its exclusion in Israel, influenced by social and cultural factors (Plutzer et al., 2020). Students often struggle with understanding DE due to difficulties in connecting microscopic interactions to macroscopic phenomena (Wilensky & Resnick, 1999; Friedler et al., 1987). Computational models, though scarce in current curricula, are identified as valuable tools for enhancing systemic understanding of DE. The study emphasizes the prevalence of SD for describing quantitative relationships in chemical and physical phenomena, while ABM is more suited for illustrating bottom-up interactions in biology and physics. SBF, primarily used in US biology and chemistry, connects the structure, behavior, and function of systems. The research concludes with recommendations to develop unified representations of DE that are adaptable across disciplines, enhancing consistency and comprehension. Future studies should explore DE's integration with other scientific concepts and its application to additional fields beyond biology, chemistry, and physics. This effort could expand the educational impact of DE by addressing its complexity through universal frameworks that bridge various scientific domains.

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