Dynamic Equilibrium Across Systems: A Narrative Literature Review of Students' Difficulties and Conceptual Challenges

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Abstract: This literature review investigates students' challenges in understanding dynamic equilibrium (DE) across biology, chemistry, and physics. DE describes systems maintaining stability through ongoing opposing processes. Our goal was to identify whether students' difficulties are phenomenon-specific or reflect cross-disciplinary structural and representational issues. Fifty-four empirical studies were analyzed using deductive and inductive coding, focusing on six representative phenomena: homeostasis and ecological balance (biology), chemical equilibrium and diffusion (chemistry), and constant electric current and uniform motion (physics). Student difficulties were synthesized into six cross-disciplinary themes, organized into two categories: (1) Understanding complex systems (A.1–A.4, 75.5% of the studies), including viewing systems as compartmentalized, confusing micro- and macro-levels, misunderstanding feedback, and perceiving equilibrium as static; (2) Mathematical perspectives (B.1–B.2, 22.1% of the studies), involving confusion base quantities with rates of change and rigid application of procedures without conceptual understanding, We propose cross-disciplinary DE representations emphasizing levels, emergence, and feedback to understanding.

Introduction

Are students' struggles with chemical equilibrium really different from their struggles with homeostasis, or from making sense of constant motion in physics? At first glance, these phenomena appear distinct—one involves reversible reactions, another the regulation of living systems, and a third the motion of objects. Yet all describe dynamic equilibrium (DE), defined as a pattern in which systems remain stable through ongoing opposing processes (Biology Dictionary, n.d.)—for example, the body releasing insulin when glucose rises and releasing glucose when it falls. This framing captures both open and closed systems, making it useful for cross-disciplinary teaching and learning. This paper examines whether students' difficulties in understanding DE share common sources. DE lies at the heart of science education, offering a lens to explain how systems maintain stability amid constant change. It is highlighted in the NGSS (2013) as one of seven cross-cutting concepts: "For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study." In prior work, we found that 17% of phenomena in high-school science concern DE directly (Dawud, Gök, Wilensky, & Levy, 2025), underscoring its centrality.

Students often face similar difficulties across systems. A key challenge is the apparent contradiction between macroscopic stability and the microscopic activity maintaining it (Sarıçayır, Şahin, & Üce, 2006). Stability is frequently interpreted as absence of change, rather than the product of dynamic interactions. For instance, chemical equilibrium may be seen as complete cessation of reactions (Nakhleh, 1992; Özmen, 2008), while homeostasis may be viewed as static rather than active regulation (Zion & Klein, 2015). Fragmented textbook representations further hinder understanding (Dawud et al., 2025); rate-based equations describe ecosystem and chemical balance, gradients drive diffusion, and feedback loops explain homeostasis. These diverse approaches obscure shared structures, limiting transfer. Another widespread difficulty concerns DE's emergent nature, requiring coordination across micro-level interactions and macro-level system patterns. Students often exhibit 'levels slippage,' attributing system-level behavior to individual agents (Wilensky & Resnick, 1999), as in diffusion misconceptions where molecules are perceived as having global knowledge (Chi et al., 2012). Additional misconceptions include framing DE as equality in amounts rather than equality in opposing process rates, observed in chemistry and biology (Soderberg & Price, 2003).

These persistent challenges motivate a comprehensive review of the literature on students' understanding of DE. This narrative review investigates whether difficulties transcend disciplinary boundaries in biology, chemistry, and physics, seeking common underlying themes rather than discipline-specific issues. Part of a broader project on DE representations, this review synthesizes 54 empirical studies to provide a coherent map of where and why students struggle, informing the design of representations that foster transferable understanding.

Methods

This study employs a narrative literature review, suitable for broad, exploratory, interdisciplinary overviews rather than narrow-focused inquiries (Collins & Fauser, 2005). This method identifies main themes across journal papers, with the search ending when thematic saturation is judged to be reached (Baumeister & Leary, 1997).

A previous investigation found 256 distinct phenomena in high-school biology, chemistry, and physics textbooks (Dawud et al., 2025). Reviewing all was unfeasible; we selected two phenomena per discipline considered prime examples of DE by the complex systems and science education communities: homeostasis and ecological balance in biology; chemical equilibrium and diffusion in chemistry; constant electric current and uniform motion in physics. Uniform motion was included to test DE across all systems, not only complex ones. The analysis incorporated both deductive and inductive coding.

Four databases were searched for peer-reviewed empirical studies on students' understanding of DE: Google Scholar, ERIC, Web of Science, and Scopus. The review includes 54 papers from 23 journals. To ensure coverage, 22 key science education journals were also scanned, and experienced researchers highlighted central studies. Selection involved a two-stage screening: titles and abstracts first, then full-text evaluation. Inclusion criteria were: (1) empirical data on students' understanding of DE; (2) use of at least one of: concepts, conceptualization, understanding, knowledge, perception, misconception, alternative conception, or mental model; and (3) mention of "dynamic equilibrium" or related phenomena (homeostasis, ecosystem balance, chemical equilibrium, diffusion, electric current, uniform motion).

Deductive coding drew on prior theories of misconceptions and systems thinking; inductive coding identified new patterns of student reasoning. Coding was initially conducted separately for each phenomenon. Difficulties were logged in spreadsheets with sources, examples, age-groups, and other details. Two researchers coded independently, and 20% of data were double-coded, yielding observed agreement P_0 = .92 and Cohen's κ = .84, indicating very good reliability (Landis & Koch, 1977). Discrepancies were resolved through iterative team discussions. Finally, initially coded themes (Holism, levels confusion, feedback misunderstanding, static view, quantity vs. rate, proceduralism) were organized into higher-level categories according to the nature of the difficulty. Examples of these coding tables are presented in the Results section.

Results

Data analysis proceeded in two stages. First, students' difficulties were identified and categorized according to specific DE phenomena. Next, these were coded and consolidated into three overarching categories, each encompassing theme that reflected common reasoning patterns. Table 1 presents a summary of these categories and themes, listing the associated phenomena, concise descriptions of the difficulties, and key supporting studies.

Table 1
Categories and Themes of Students' Difficulties in Understanding Dynamic Equilibrium by Phenomenon

Category and Theme	Phenomenon	Alternative Concepts	Studies
A. Understanding complex systems A.1 System as compartmentalized instead of as an interacting whole.	Homeostasis	The body is controlled by the brain alone.	[7]
	Ecology	Ecosystems are static, or go through very slow changes; feedback is not described	[9], [12], [13]
	Chemical equilibrium	The processes that the reactant and product molecules undergo are separate from each other.	[16], [17], [20], [25]
		Reactants molecules get fully used up at equilibrium.	[17], [24]
	Electric current	Circuits are static; focus on the hardware (battery, bulb).	[34]
A. Understanding complex systems A.2 Levels confusion: assigning macro-level behavior to micro-level entities.	Homeostasis	Focus on external direct causes; missing internal regulation	[4], [6]
	Ecology	Can't link individual actions to ecosystem effects.	[9], [13]
	Electric current	No microscopic view; unaware of electron movement.	[33]
A. Understanding complex systems A.3	Homeostasis	Explain equilibrium via external factors only; missing feedback.	[5], [6]
		Confuse controlled variable and control input.	[2]
	Ecology	One-way interactions in food webs, ignoring feedback and indirect effects.	[9], [10], [11], [12], [13]

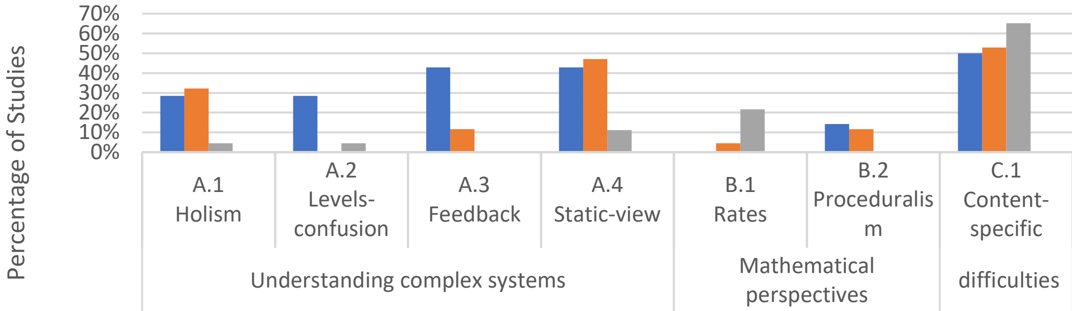
Category and Theme	Phenomenon	Alternative Concepts	Studies
Misunderstanding feedback	Chemical equilibrium	Equilibrium shifts not linked to feedback, thinking they occur independently of regulatory processes.	[16], [25]
A. Understanding complex systems A.4 Systems are static when they are in equilibrium, ignoring the micro-level processes and changes that are taking place.	Homeostasis	Equilibrium seen as static; not as ongoing processes.	[2], [5], [7]
	Ecology	Population levels in an ecosystem are fixed; fluctuations are ignored.	[11], [12], [13], [14]
	Chemical equilibrium	Reaction stops at equilibrium; ignoring reaction in the opposite direction.	[15], [17], [18], [20], [21], [23], [24]
	Diffusion	Particle motion stops at equilibrium.	[29], [31]
	Uniform motion	An external force is needed to maintain constant velocity.	[48], [51], [52]
B. Mathematical perspectives B.1 Confusing base quantities with rate of change.	Chemical equilibrium	Equilibrium is reached when there are equal concentrations of the reactants and products; rather than ascribing equilibrium to equal reaction rates.	[15], [17], [18], [19], [23]
	Uniform motion	Velocity is proportional to force; rather than acceleration.	[47], [48], [49], [50], [53]
B. Mathematical perspectives B.2 Rigid adherence to mathematical procedures with limited scientific conceptual understanding.	Homeostasis	Confuse the “negative” part of negative feedback with decrease in amount.	[3], [7]
	Chemical equilibrium	Le Châtelier’s Principle is applied mechanically, lacking conceptual grasp, e.g. confusing the “negative” part of negative feedback with decrease in amount.	[16], [25]
C. Content-related Specific C.1 Sample difficulties tied to specific content or representations.	Homeostasis	Homeostasis takes place only when the system reaches extremes.	[1], [3], [5], [7]
		Negative feedback is harmful.	[3], [7]
		Internal conditions thought constant despite external changes.	[5]
	Diffusion	Particles have intentions to homogenize concentration throughout a container.	[27], [28], [29]
		Heating thought to increase attraction between particles.	[26], [30]
		Cold water blocks the movement of ink due to increased density or viscosity.	[26], [30]
	Electric current	Current is consumed by electric circuit components.	[35], [36], [40], [43]
		Current flow decreases along wire as one gets further from the battery.	[39], [40], [41], [45]
		Electric field confused with force; field lines misinterpreted.	[32], [38], [39], [46]
	Uniform motion	Continuous force needed to sustain motion.	[52], [54]

Numbers in the “Studies” column correspond to the studies listed in the online reference link provided before the bibliography.

Synthesis of difficulties across disciplines

Students’ difficulties were consolidated into seven themes, grouped under three categories (Table 1), highlighting common challenges in reasoning about DE across biology, chemistry, and physics. Figure 1 shows the distribution of these themes across disciplines.

Figure 1
Distribution of Reported Difficulties in Understanding Dynamic Equilibrium by Categories, Themes, and Scientific Disciplines.



	A.1 Holism	A.2 Levels-confusion	A.3 Feedback	A.4 Static-view	B.1 Rates	B.2 Proceduralism	C.1 Content-specific difficulties
Biology	28.5%	28.5%	42.8%	42.8%	0.0%	14.2%	50.0%
Chemistry	32.2%	0.0%	11.7%	47.1%	4.6%	11.7%	52.9%
Physics	4.5%	4.5%	0.0%	11.1%	21.7%	0.0%	65.2%
All disciplines	20.30%	9.20%	14.80%	31.40%	14.70%	7.40%	60.90%

Results are reported in proportion (%) from N=54 papers overall, n=14 for biology, n=17 for chemistry, n=23 for physics)
Note: The total percentage exceeds 100% because several studies reported more than one type of difficulty.

Discussion

This review provides a foundational step in a broader project aimed at developing computational representations to support understanding of DE as a crosscutting concept. By identifying cross-disciplinary structural difficulties and organizing them into coherent themes, it defines design constraints that guide the development and empirical testing of these models. Clarifying these shared sources of difficulty is essential for ensuring that future representations address underlying reasoning patterns rather than isolated disciplinary content, thereby supporting transfer and coherence across science domains.

Analysis of 54 empirical studies in biology, chemistry, and physics shows that over half of reported difficulties are cross-disciplinary and structural. Six themes were grouped into two overarching categories: (1) understanding complex systems and (2) mathematical perspectives of modeling scientific phenomena. Common difficulties in complex systems include assuming centralized control, confusing micro- and macro-level behaviors, focusing on structural elements rather than mechanisms, linearizing nonlinear behaviors, and assuming deterministic rather than stochastic processes (Hmelo-Silver & Pfeffer, 2004; Jacobson, 2001). Across phenomena, perceiving equilibrium as static (A.4, 31.4%) and lacking a holistic perspective (A.1) were most frequent; feedback misunderstandings (A.3, 14.8%) appeared mainly in biology, rarely in chemistry, and not in physics, consistent with curricula and NGSS attention (Giancoli, 2016; Hewitt, 2009; NGSS Framework, 2013).

Mathematical difficulties (B.1–B.2, 22.1%) include confusing base quantities with rates and rigid procedural application without conceptual understanding, consistent with proceduralism (Mason, Shell, & Crawley, 1997; Niaz, 2001). Instructional research suggests supporting qualitative interpretation of rates, symbolic forms, and algebraic reasoning to foster deeper understanding (Kuo, Hull, Gupta, & Elby, 2013; Eichenlaub, Redish, & Bao, 2019; Avgerinos & Remoundou, 2021).

Synthesizing these findings lays the groundwork for designing multi-level, integrated, cross-disciplinary representations that foreground shared system features of DE—feedback, gradient-driven change, opposing influences, and rate balance. While this review did not test interventions, literature indicates that tasks prompting cognitive conflict and qualitative reasoning can remediate structural difficulties (Niaz, 2001). Framing DE as a unifying, emergent pattern across disciplines offers a path to enhance coherence, transfer, and integrated understanding in science education, consistent with NGSS crosscutting concepts (NGSS, 2013).

Note: Owing to space limitations, a comprehensive list of the studies referenced in Table 1 can be accessed via the following link. The reference section below includes only the sources cited in the main text. Can be accessed via the following link:
https://drive.google.com/file/d/1IWEVMSEAZenqMR7zXzAWPnpGxeP82mYI/view?usp=sharing

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