Comenius University in Bratislava
Faculty of Mathematics, Physics and Informatics

Educational tool for system thinking

Bachelor Thesis

2026

Daniiar Sherniiazov

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Study Programme:	Computer Science
Field of Study:	Computer Science
Department:	Department of Computer Science
Supervisor:	doc. RNDr. Martin Takáč, PhD.

Bratislava, 2026
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Univerzita Komenského v Bratislave
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ZADANIE ZÁVEREČNEJ PRÁCE

Meno a priezvisko študenta:	Daniiar Sherniiazov
Študijný program:	aplikovaná informatika (Jednoodborové štúdium, bakalársky I. st., denná forma)
Študijný odbor:	informatika
Typ záverečnej práce:	bakalárska
Jazyk záverečnej práce:	anglický
Sekundárny jazyk:	slovenský

Názov: Educational tool for system thinking
Výuková pomôcka pre systémové myslenie

Anotácia: Systémové myslenie je spôsob konceptualizácie komplexnej reality v zmysle celkov, vzťahov, spätných väzieb a generických štruktúr s využitím konceptov z teórie riadenia a regulácie, kybernetiky a dynamických systémov a je široko využívané v environmentálnych, politických, sociálnych vedách a ekonomike. Cieľom tejto práce je skúmať základné generické systémové štruktúry (archetypy) a nájsť spôsob, ako ich prezentovať a vizualizovať na vzdelávacie účely.

Cieľ:
1. Naštudovať základy teórie systémov
2. Urobiť prehľad existujúcich simulačných prostredí
3. Vytvoriť teoretický návrh scenárov pre výukovú pomôcku
4. Implementovať názornú výukovú vizualizačnú pomôcku pre navrhnuté scenáre

Literatúra:
D. H. Meadows: Thinking in systems: A Primer. Earthscan, 2009.
M. Caha:Systémy pro všední den. Gemmapress, Praha, 1999.
R. Pelánek: Modelování a simulace komplexních systémů. Nakladatelství Masarykovy univerzity, 2011.

Vedúci:	doc. RNDr. Martin Takáč, PhD. (od 17.03.2025)
Katedra:	FMFI.KAI - Katedra aplikovanej informatiky
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Dátum zadania:	27.03.2025
Dátum schválenia:	07.04.2025

doc. RNDr. Damas Gruska, PhD.
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THESIS ASSIGNMENT

Name and Surname:	Daniiar Sherniiazov
Study programme:	Applied Computer Science (Single degree study, bachelor I. deg., full time form)
Field of Study:	Computer Science
Type of Thesis:	Bachelor´s thesis
Language of Thesis:	English
Secondary language:	Slovak

Title: Educational tool for system thinking

Annotation: Systems thinking is a way of conceptualizing complex reality in terms of wholes, relationships, feedback loops and generic structures using concepts from control and regulation theory, cybernetics and dynamical systems and is widely used in environmental, political, social sciences and economy. The goal of this thesis is to study basic generic system structures (archetypes), finding a way how to present and visualise them for educational purposes.

Aim:
1. Learn the basics of systems theory
2. Review existing simulation environments
3. Create a theoretical design of scenarios for a teaching tool
4. Implement an illustrative educational visualization tool for the designed scenarios

Literature:
D. H. Meadows: Thinking in systems: A Primer. Earthscan, 2009.
M. Caha:Systémy pro všední den. Gemmapress, Praha, 1999.
R. Pelánek: Modelování a simulace komplexních systémů. Nakladatelství Masarykovy univerzity, 2011.

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Assigned:	27.03.2025
Approved:	07.04.2025

doc. RNDr. Damas Gruska, PhD.
Guarantor of Study Programme

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Acknowledgments: I would like to thank my supervisor doc. RNDr. Martin Takáč, PhD. for his help during work on the bachelor thesis.

Abstract

This bachelor thesis explores the fundamental principles of systems thinking and demonstrates their practical application through the development of a web-based educational tool. The theoretical background introduces key concepts such as stocks, flows, and feedback loops, emphasizing their role in modeling and understanding dynamic systems. Existing solutions are reviewed and analyzed for their pedagogical approaches and technical implementations. Building on these insights, the year project presents the design and implementation of an interactive web application that enables users to construct, simulate, and analyze systems visually. The frontend will be designed to offer a user-friendly, modular interface, while the backend focuses on robust data management, secure user authentication, and ongoing progress tracking. Together, these components form a unified solution that connects theoretical foundations with practical engagement, helping both learners and teachers to explore systems thinking in an accessible and interactive environment.

Keywords: systems thinking, educational web tool, dynamic systems, simulation, system modeling, feedback loops, stocks and flows, interactive learning, React, Python, educational technology, user experience

Abstrakt

Táto bakalárska práca sa zaoberá základnými princípmi systémového myslenia a demonštruje ich praktické využitie prostredníctvom vývoja webového vzdelávacieho nástroja. Teoretická časť predstavuje kľúčové pojmy ako zásoby (stocks), toky (flows) a spätné väzby (feedback loops), pričom zdôrazňuje ich význam pri modelovaní a porozumení dynamickým systémom. Existujúce riešenia sú preskúmané a analyzované z hľadiska ich pedagogických prístupov a technickej implementácie. Na základe týchto poznatkov projekt opisuje návrh a implementáciu interaktívnej webovej aplikácie, ktorá umožňuje používateľom vizuálne vytvárať, simulovať a analyzovať systémy. Frontend je navrhnutý s dôrazom na používateľskú prívetivosť a modulárnu architektúru, zatiaľ čo backend je zameraný na spoľahlivé spracovanie dát, bezpečné overovanie používateľov a priebežné sledovanie pokroku. Výsledkom je komplexná platforma, ktorá prepája teoretické vedomosti s praktickým učením a robí systémové myslenie prístupnejším a atraktívnym pre študentov aj pedagógov v interaktívnom prostredí.

Kľúčové slová: systémové myslenie, webový vzdelávací nástroj, dynamické systémy, simulácia, modelovanie systémov, spätné väzby, zásoby a toky, interaktívne učenie, React, Python, vzdelávacie technológie, používateľská skúsenosť

Contents

List of Figures

List of Tables

Introduction

In today's world, there are numerous global-scale problems from social to environmental that are not only deeply complex within themselves but also intricately interconnected with other issues. Even small changes in one part of a system can lead to major shifts elsewhere. In such an interconnected reality, it becomes natural to view everything as part of a broader system.

Systems thinking is an approach that helps recognize chains of interrelated elements, understand their dynamic behavior, and steer them toward desired outcomes. It is not merely a set of methods or models for identifying systems, but a fundamentally different way of perceiving the world - one that enables the recognition of recurring patterns, anticipation of consequences, and identification of leverage points for positive systemic change.

The roots of systems thinking trace back to the pioneering work of thinkers such as Ludwig von Bertalanffy [11] and Jay W. Forrester [2], who each contributed foundational concepts in general systems theory and system dynamics. A key figure in the development and popularization of the systems approach was Donella Meadows, whose widely acclaimed book Thinking in Systems [5] remains a vital resource for both students and professionals seeking to understand and apply systems-based approaches.

The aim of this project is to present the core principles of systems thinking and to illustrate their interrelations through a web-based educational tool. This tool will allow users to explore system components, understand how feedback loops function, identify typical systemic traps, and learn how to construct effective models based on real-world systems. This educational tool will be implemented as a web application, with its technologies detailed in the Sources section.

Chapter 1

Sources

This chapter presents the theoretical foundation of the thesis, reviews similar existing solutions, and describes the technologies used in the implementation.

1.1 Concepts of system thinking theory

What is a system? D.H. Meadows gives us a very simple but powerful definition: "A system is a set of things - people, cells, molecules, or whatever interconnected in such a way that they produce their own pattern of behavior over time."[5]

A system consists of elements, interconnections, and its function.

Elements form the basis of a system; they are the entities the system operates upon, and within the boundaries of that system, they can represent virtually anything. Interconnections refer to the relationships among system elements. These links are not always visible or tangible, yet they are essential because they illustrate how elements affect one another. Function is no less important in understanding a system. It gives the system its purpose and defines how it will behave in the future.

A very important point made by D.H. Meadows is: "A system is more than the sum of its parts."

This idea refers to the concept of emergence. Emergence is a property of systems where structured elements create new behaviors that none of the elements possess individually. For example, consider a group of students in a classroom. As a class, they begin to exhibit new behaviors such as following school discipline, forming group dynamics with leaders and outsiders, and developing characteristics unique to that specific group. Each individual student alone would not exhibit these systemic traits—but together, they create a new behavioral structure.

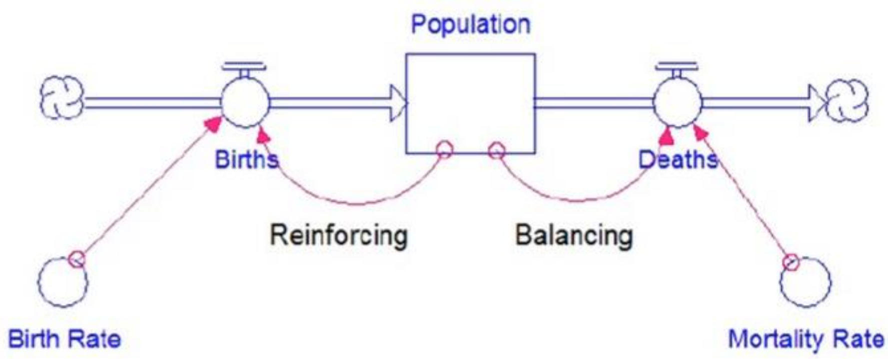

Figure 1.1: Feedback loops are represented by red arrows (except for the arrows from Birth rate and Mortality rate). Large blue arrows denote the direction of flows. Circles with tap icons symbolize flow variables, while the square represents a stock.

1.1.1 Fundamentals

To understand how systems operate, it is also important to grasp a few additional concepts: stocks and flows.

- A stock is a valuable resource held within a system. It often has a limited quantity and can be either renewable or non-renewable. Its level can increase or decrease over time.
- A flow represents the movement or change of stocks. It is similar to water flowing from a faucet: it has a capacity, and it can either add to or reduce the amount of stock.

Therefore, flows are categorized into inflows and outflows.

The current level of a stock usually correlates with the historical behavior of its flows.

While stocks and flows help us understand what is changing in a system and by how much, they do not explain why systems often behave in nonlinear ways. To understand this, we need to explore the concept of feedback loops these are the consequences of an action that come back to influence the system in the future. Sometimes the effects of feedback are immediate, while in other cases they appear after a significant amount of time. This delay in response is referred to as a delay. There are two main types of feedback loops:

- Reinforcing feedback loop: This type of loop amplifies change, driving exponential growth or decline. For example, reinforcing feedback loop rewards the winner of a competition with the means to win further competitions [5].
- Balancing feedback loop: Balancing processes seek equilibrium: They try to bring things to a desired state and keep them there [4]

In real-world systems, feedback loops don't operate in isolation. Instead, numerous reinforcing and balancing loops are deeply interconnected, each influencing the others. A lot of different feedbacks can give rise to dynamic behaviors that are difficult to predict, such as oscillations.

1.1.2 System Behavior

All systems, in addition to being composed of various components, also possess their own properties. These properties may impose constraints or, conversely, allow certain flexibility in the system's design. They describe the system's structure, as well as its capacity for self-modification and self-regulation. Let's consider the first property.

Resilience

Resilience is a base to the endurance of a system. It enables the system to withstand changes that may result from adverse conditions; it is the system's ability to adapt to challenging environments while maintaining its integrity and continuing to fulfill its core function. Importantly, resilience is not merely the ability to avoid or defend against change. Rather, it is the capacity of a system to transform itself in ways that allow it to absorb disturbances and still retain its essential identity and purpose.

D.H Meadows writes:

> Resilience is not the same thing as being static or constant over time. Resilient systems can be very dynamic. Short-term oscillations, or periodic outbreaks, or long cycles of succession, climax, and collapse may in fact be the normal condition, which resilience acts to restore!

[5]

Self-Organization

Self-organization is a key property of many complex systems. It refers to the ability of a system to restructure itself, develop new patterns of behavior, or even generate entirely new components, all without direction from an external authority or central controller. Self-organization is a fundamental process that is virtually impossible to eliminate from a system, as it is intrinsic to how systems evolve and adapt.

Hierarchy

Nearly all complex systems exhibit a hierarchical structure, meaning they are organized into layers—systems nested within systems. Each layer, or subsystem, may itself contain even smaller subsystems. This organization allows large and complex systems to remain coherent and manageable, as it distributes responsibilities across multiple levels. A well-designed hierarchy strikes a balance between autonomy and integration: subsystems are able to function independently within their boundaries, while also working together to achieve the objectives of the overall system. This structure enhances both resilience and efficiency. However, excessive centralization or lack of coordination between layers can reduce a system's adaptability and slow its response to change.

System Boundaries

Every system possesses boundaries. These are not always immediately apparent, as they are often conceptual or artificial rather than physical. Nevertheless, boundaries play a critical role. They must be carefully defined—not too narrow, so as to overlook important influences, nor too broad, which could blur the focus of analysis. Properly established boundaries separate the system under consideration from its environment and external influences, enabling meaningful analysis and effective management. A boundary doesn't necessarily mark a hard edge, but rather a chosen scope of attention defined by the purpose of the analysis.

"boundaries are of our own making, and that they can and should be reconsidered for each new discussion, problem, or purpose"[5]

1.1.3 Practical use of system thinking

Systems thinking can be applied broadly across many areas of life. For example, there are well-documented use cases for its application in healthcare [9] and agriculture [1].

One of the key strengths of systems thinking is its ability to help us identify leverage points—specific places within a system where a small adjustment can produce significant outcomes. To discover these leverage points, it's important to carefully analyze how the system functions as a whole. Sometimes, the most impactful change comes not from large interventions, but from shifting the system's goals, enhancing information flow, refining feedback mechanisms, or challenging the core assumptions that drive the system's behavior.

A central idea in systems thinking is to search for opportunities that allow us to create meaningful improvements by aligning our actions with the system's natural dynamics rather than pushing against them. In many cases, substantial progress results from subtle, targeted changes—such as fostering better communication, altering decision-making processes, or redefining priorities.

At the same time, it is crucial to be aware of system traps—recurring patterns of dysfunction that are rooted in a system's underlying structure. Examples of these traps include escalation (when issues keep intensifying), shifting the burden (addressing symptoms instead of root causes), and the tragedy of the commons (where shared

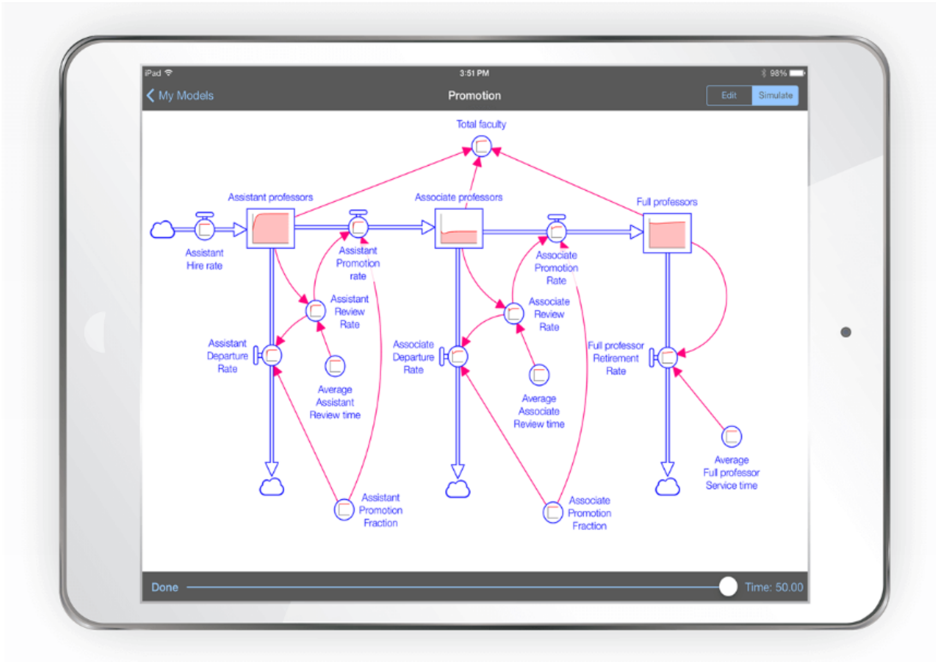

Figure 1.2: Example of STELLA [3] user interface and system creation

resources are depleted through overuse). Failure to recognize these traps can lead to solutions that inadvertently worsen the problem. Effective systems thinking involves being able to spot these patterns early and addressing their fundamental causes, rather than merely treating the visible symptoms.

1.2 Existing solutions

The web application will function as an interactive online tool for building systems, integrated with an educational course. Its user interface and controls will draw inspiration from tools, which are described in the following sections.

1.2.1 Similar web applications

STELLA

STELLA [3] (Systems Thinking, Experimental Learning Laboratory with Animation), created by isee Systems, is educational software emphasizing visualization and understanding of complex dynamic systems through an intuitive graphical modeling environment.

STELLA's courses and modules typically teach core concepts such as feedback loops, stocks, and flows, foundational for understanding system dynamics. Exercises are scenario-based, enabling learners to visually observe and actively explore how systems behave over time.

While STELLA effectively introduces essential principles, advanced theoretical backgrounds are generally discussed less extensively, assuming users possess some prior knowledge or concurrently study theory elsewhere.

STELLA actively promotes experiential learning by allowing students to modify parameters and immediately visualize consequences, making theoretical principles clear through interaction. It also supports publishing interactive models online, although detailed feedback or peer review mechanisms are not inherently integrated.

The interface of STELLA is user-friendly and education-oriented, employing clear visual icons and diagrams, neatly dividing the workspace into areas for model creation, parameter input, and simulation output (graphs and animations). This delivers an intuitive, engaging learning experience, clearly communicating complex ideas through visual elements.

LOOPY

LOOPY [8], developed by designer Nicky Case, positions itself as a highly accessible entry-point for teaching and experimenting with systems thinking using causal loop diagrams (CLDs). It emphasizes simplicity and direct interactivity.

LOOPY provides a general-purpose canvas to freely visualize causal relationships. It implicitly introduces learners to fundamental systems concepts through immediate visual feedback in simulations rather than structured coursework.

LOOPY offers users a straightforward "sandbox" experience where they can quickly sketch and animate system interactions. This approach is particularly valuable for beginners who prefer learning through direct experimentation without extensive theoretical introductions.

LOOPY does not directly support formal feedback mechanisms. Sharing primarily occurs through simple URL-based model distribution. The emphasis is placed entirely on visual intuition and user-driven experimentation.

The user interface of LOOPY is simple, intuitive, and visually appealing, characterized by minimalistic graphics and playful animation. Its workspace consists primarily of a single interactive pane, where users directly create and animate causal diagrams, offering immediate engagement and visual feedback.

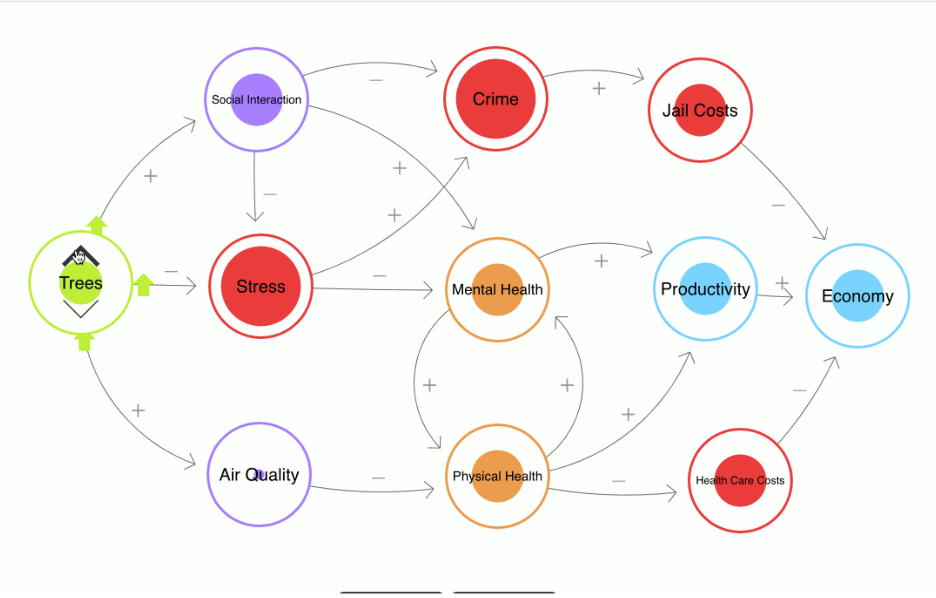

Figure 1.3: Example of LOOPY [8] user interface and system creation

Silico

Silico [10] is a contemporary web-based platform aimed at simplifying the modeling and simulation of system dynamics. It presents itself as a modern, user-friendly educational and modeling tool, providing a streamlined environment for dynamic system exploration and learning.

Silico emphasizes practical modeling skills, scenario analysis, and direct visualization of dynamic systems. The platform enables broad conceptual experimentation, supporting the modeling of diverse real-world systems. Foundational theoretical concepts and rigorous academic theories underlying systems thinking are often implicitly embedded rather than explicitly taught through extensive written materials.

Silico actively promotes exploratory learning, allowing immediate visualization of model dynamics. Users can quickly create system diagrams, adjust parameters, run simulations, and analyze outcomes through integrated real-time graphs. Structured feedback mechanisms or peer review features are not directly supported within the platform.

Silico's interface provides a clean and accessible environment, clearly divided into visual modeling sections, parameter input panels, and dynamic visualization areas. The intuitive design supports seamless, engaging experiences for users at various expertise levels, facilitating effective dynamic system exploration.

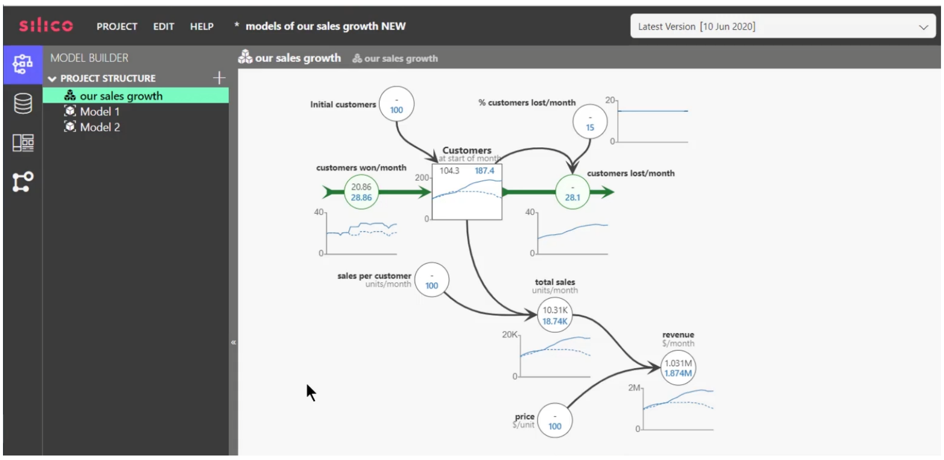

Figure 1.4: Example of Silico [10] user interface and system creation

1.3 Technologies that can be used

The technologies that will be applied in the web-based system thinking educational tool are described and assessed in the next subsections.

1.3.1 Client

This section details the technologies chosen for constructing the client side of the application.

React

The client-side application leverages React, an open-source frontend library for web and native user interfaces [6] maintained by Meta and the developer community. React's component-based architecture enables the creation of dynamic, interactive, and modular user interfaces, supporting a high degree of flexibility and reusability in UI development.

TypeScript

Development is conducted entirely in TypeScript, a statically-typed superset of JavaScript. TypeScript is a strongly typed programming language that builds on JavaScript, giving better tooling at any scale [7]. Before deployment, TypeScript code is transpiled into standard JavaScript for execution in browsers.

1.3.2 Server

The server component

Conclusion

This thesis has examined the key principles of systems thinking and their importance in understanding complex, interconnected problems. As part of the project, I researched and selected appropriate web development technologies to create an interactive application capable of modeling real-world systems. The goal was to design a tool that clearly represents essential system elements such as feedback loops and dynamic behavior.

The result of this work is a functional educational tool that connects theory with practice. It shows that systems thinking is not just an abstract academic concept but a practical approach that can be applied to solve real problems across various fields. Instead of focusing on individual parts in isolation, systems thinking helps us understand how elements interact and influence one another.

In future versions of the tool, the learning experience could be improved by allowing users to share their own system models. It would also be beneficial to include case studies from different areas such as environmental systems, economics, or social structure to demonstrate how systems thinking can be applied in different contexts.

Overall, this thesis highlights that systems thinking is a valuable mindset for dealing with the complexity of today's world. By recognizing how everything is connected and how actions can have long-term and unexpected effects, we can make more thoughtful decisions and develop more sustainable solutions.

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