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AI Competencies Through the Lens of Systems Thinking Integration in Pre-service Teachers' Education

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Abstract

This paper presents a flexible, generic conceptual framework, combining the Cynefin model and feedback loops, to develop systems thinking and AI competencies in Gen Z pre-service teachers. Serving as both a learning design space and a foundation for educational materials, it supports preparing future educators to navigate complexity and address sustainability challenges in evolving societal contexts.

Keywords: AI competencies, Cynefin framework, feedback loops, pre-service teachers, systems thinking

Introduction

Central to the 2030 Agenda for Sustainable Development is the emphasis on systems thinking as a foundational tool for navigating complexity and uncertainty (Cabrera & Cabrera, 2023). Although complex systems entail interacting components, they cannot be considered in isolation. Through their interplay the system's behaviors evolve in a nonlinear and unpredictable way upon feedback loops.

The notion of feedback loops refers to modeling the interactions in a system in a way that allows us to understand how a change in one component of a system influences others, which in turn loop back to influence the initial one (Meyer, 2012). Two main types of feedback loops are considered, the reinforcing (positive) loop and the balancing (negative) loop (Zhing Liew et al., 2024). The polarity of the loops reflects the described behaviour, i.e., the positive one reinforces change either increasing or decreasing, denoting acceleration of the influence of one component to another and the latter to the first one. Such behaviour is escalated in time and leads to instability of the system. The negative polarity denotes the opposite behaviour, i.e., restrains the change and contributes to stabilization. In this way actions and interactions within the system can be mentally conceived. However, a third case of feedback loop, includes a time delay between the action and reaction, helping to realize the way that delayed responses may influence the system's behaviour.

The Cynefin is a conceptual framework that provides five domains of decision making upon a typology of problems of varied complexity (Snowden, 1999). This conceptualization aims at sense-making of the complexities in each domain and act accordingly as follows: (a) the *clear* domain (*sense-categorize-respond*). The cause effect is clear, so sense by realizing the facts, categorizing and responding based on the best-known practice, (b) the *complicated* domain (*sense-analyze-respond*). The cause effect is not understood straightforwardly. An expert can analyze this relationship from multiple perspectives upon expertise and the available facts, (c) the *complex* domain (*probe-sense-respond*). This domain is defined by emergence, thus the relationship between cause and effect can only be understood in retrospect upon processes like experimentation, collaboration and reflection, (d) the *chaotic* domain (*act-sense-respond*). There is not any cause effect relationship. Leadership and clear communication are critical in this domain towards on time actions, (e)the *aporetic* (confused) domain. There is confusion as to which domain of the framework applies. Sensemaking helps

to deal with this uncertainty by gathering data, consideration of multiple perspectives, collaboration and experimentation to realize the context before acting.

UNESCO highlights the imperative to embed sustainability competencies (i.e., Knowledge (K), Skills (S) and Values (V)), across Higher Education Institutions (HEIs), while UNECE places special emphasis on integrating them into pre-service teachers' education-recognizing educators as the architects of future generations. However, sustainability remains underrepresented in HEI curricula, further compounding the challenge of preparing educators to foster these competencies.

In this work the Cynefin framework is combined with the notion of feedback loops to provide a systems thinking perspective in the educational context of pre-service teachers. To our knowledge only Zhing Liew et al., (2024) used the notion of the feedback loops, to examine the intricate interplay between AI integration and the landscape of higher education, yet without considering complexity as in the Cynefin framework.

The proposed conceptual framework

Based on the aforementioned background, we propose here a conceptual framework as depicted in Figure 1.

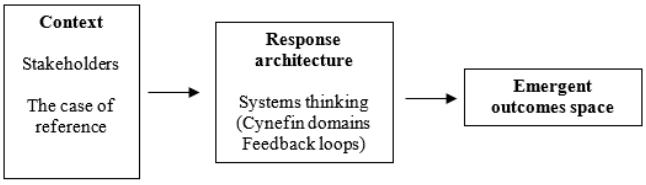

Figure 1. The proposed conceptual framework

In particular, the proposed conceptual framework constitutes a learning design space that employs systems thinking in a complex context of reference. This framework can be used in education to design learning experiences and/or materials towards the case of reference that is considered as a complex system. Based on Cynefin domains and feedback loops, emergent outcomes upon the case of reference are anticipated in the outcomes space. This framework puts in use the mindset of systems thinking upon real-world cases. The flexibility of this parsimonious framework allows for the use of different cases at various levels of complexity and locality as compared to the context of reference. In the next section, the case of AI competencies cultivation in a pre-service teachers HEI is presented.

Cases on pre-service teachers' AI competencies

In Figures 2-5 five cases are described that can serve as examples of the proposed conceptual framework, towards the cultivation of AI competencies upon UNESCO's (2024) framework. The proposed conceptual framework constitutes a learning design space for the cultivation of AI competencies to any interested stakeholder in an educational ecosystem, e.g., student, teacher, anyone holding educational leadership, educational policy maker, considering AI integration to the everyday work, as a complex issue of varying complexity.

Upon specific case of reference, the response architecture of the proposed framework employs the realization of the Cynefin domain, relevant sense and decision making upon the identification of positive, negative and possibly delay feedback loops in the context.

Clear Domain (Ordered, Known relationships)

Context: Automated grading and quiz generation in LMS

- *Positive Loop*: Using AI for formative assessments improves grading efficiency → more frequent testing → improved feedback cycles.
  [K: Understand AI functions in education]
- *Negative Loop*: Overuse of AI-generated quizzes leads to content repetition → student disengagement → teachers manually intervene.
  [S: Manage AI tools in classroom contexts]
- *Delay Loop*: Initial time saved is offset by delayed realization of reduced content depth → triggers policy on quality control months later.
  [V: Maintain responsibility in AI usage]

Figure 2. The clear domain case

Complicated Domain (Multiple right answers, expert knowledge needed)

Case: AI-driven lesson planning analytics

- *Positive Loop*: Teachers use AI analytics to optimize instruction → better alignment with student needs → measurable gains → reinforced AI use.
  [S: Apply AI tools for teaching design]
- *Negative Loop*: Blind reliance on AI insights undermines pedagogical judgment → faculty intervenes with critical review rubrics.
  [V: Encourage transparency and human oversight)
- *Delay Loop*: Data from AI usage takes a semester to accumulate → adjustments based on patterns only made in the next academic year.
  [K: Recognize limitations of AI systems]

Figure 3. The complicated domain case

Complex Domain (Emergent, Nonlinear)

Context**:** Co-designing feedback systems with AI during practicum

- *Positive Loop*: PSTs adapt AI tools to student feedback → students engage more → PSTs gain confidence → more innovation.
  [S: Innovate with AI tools in educational settings]
- *Negative Loop*: Misinterpretation of AI-generated sentiment leads to miscommunication → students lose trust → PSTs refine model.
  [V: Promote fairness and inclusivity in AI]
- *Delay Loop*: Full impact of student trust-building visible only after extended interactions → adjustments visible post-practicum.
  [K: Understand socio-technical implications]

Figure 4. The complex domain case

Chaotic Domain (Crisis, Urgency)

Context: Emergency AI deployment in remote teaching (e.g., pandemic)

- *Positive Loop*: AI tools maintain educational continuity → institutional trust grows → more digital investment.
  [S: Use AI to ensure learning access]
- *Negative Loop*: Overdependence on automated tools erodes teacher-student interaction → burnout increases → return to blended models.
  [V: Maintain educator agency in crisis]
- *Delay Loop:* Long-term emotional disconnect surfaces months later → psychological and pedagogical reforms follow.
  [K: AI risks under emergency]

Figure 5. The chaotic domain case

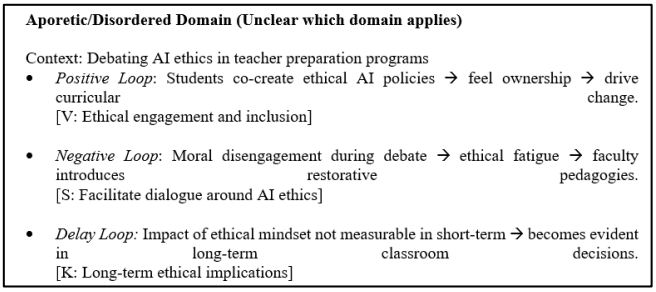

Figure 6. The aporetic domain case

This procedure supports capturing the dynamic nature of the AI integration in the educational ecosystem at the level of reference (e.g., the classroom, the school, etc.) and entails the cultivation of AI competencies. The emergent outcome space refers to the cultivation of AI competencies though the interaction of the interested stakeholder/s with the response architecture.

Conclusions

A flexible conceptual framework, tailored to Generation Z's profile, is introduced to cultivate systems thinking to pre-service teachers. The framework supports exploring diverse cases, serving both as a learning space and a basis for educational material design. The case of AI integration to pre-service teachers is used to exemplify the proposed approach. This work initiates part of the theoretical background of a research program, where forthcoming pilot studies, incorporating 300 pre-service teachers, are expected to provide empirical evidence on the framework's effectiveness.

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