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Competence Modelling From the Perspective of Complex Systems Theories: A Systematic Literature Review

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Annotation. This study aims to comprehend how competence can be conceptualised and modelled from the perspective of complex systems theories in a volatile, uncertain, complex, and ambiguous world. Having systematically reviewed 21 studies, this research reveals aspects of complex systems in competence development research as well as introduces ways to define competence as a complex system. It also sheds light on the variety of complexity-informed models adopted for competence development research.

Keywords: *complex systems, competence, competence models, modelling, systematic literature review.*

Introduction

Competence development has occupied the focus of international debates on curricula, assessment, and learning (European Commission, 2019, OECD, 2017) as it is "one of the aims of the vision towards a European Education Area that would be able to harness the full potential of education and culture as drivers for jobs, social fairness, active citizenship as well as means to experience European identity in all its diversity" (Council Recommendations on Key Competences for Lifelong Learning, 2018, p. 1). In addition, competence assessment is considered to be essential to educational process optimisation and the advancement of the educational systems; therefore, in modern industrial societies, the focus on competence assessment has been shifting from mere

measurement of pre-defined sets of skills and capabilities to the evaluation of many more complex abilities that are ingrained in real-world contexts (Koeppen et al., 2014). However, the question remains whether the current conceptualisation of competence, as well as competence models guiding curricula in higher education institutions, correspond to the constantly changing world, also known as a VUCA world – the world of *volatility, uncertainty, complexity*, and *ambiguity* (Bennis & Nanus, 2003). To contribute to this field, this paper aims to reveal how the notion of competence is conceptualised and modelled from a complex systems point of view. The methodology undertaken to fulfil this aim is that of a systematic review of literature on complex systems in education, complexity modelling, and overall competence modelling in complexity-informed studies. The ontology of complex systems, with its emphasis on modelling methods, has been vastly employed in a wide range of areas within natural sciences, and now it has been effectively spreading to social sciences as well (Castellani & Hafferty, 2009; Byrne & Callaghan, 2014; Youngman & Hadzikadic, 2014; Aharon et al., 2015; Condorelli, 2016, etc.). There is a growing body of literature referring to complexity in education (Davis & Sumara, 2008; Mason, 2008) or education as a complex system (Jacobson & Wilensky, 2006; Lemke & Sabelli, 2008); thus, complexity has the potential to open up new conceptual and methodological perspectives in educational research. However, the use of such modelling approaches in educational sciences is still in its early days, and future work is necessary to advance the development and validation of these modelling methods to meet the needs of educational researchers as well as policy makers (Jacobson et al., 2019). This systematic literature review aims to address the following research questions which guide this study:

1. How can competence be conceptualised from the perspective of complex systems theories?
2. Which subjects are identified as complex systems in the study of competence development?
3. How can competence be characterised as a complex system?
4. Which complexity models are employed for competence development in existing literature?

Review of Literature and Theoretical Framework

Competence and Changing Educational Landscapes

Today, competence plays a central role in the European educational context. Even though the notion of competence development has existed for several decades, its definition still needs to be determined. *Competence* is often used interchangeably with terms such as *skill, outcome, behaviour* (Vitello et al., 2021), *literacy, capacity*, or *capability* (Markauskaite et al., 2022). Certain confusion is often caused by the ambiguity

of the terms *competence* and *competency*, where the former refers to "broad groups of general capacities", and the latter labels "specific performances or aspects of activities" (Hyland, 1994, p. 21). In addition, among researchers, the concept of *competence* is also used as a means to describe the shifts that are taking place in our (post-)modern world and work life, which involve new educational goals; thus, elaborate models that embrace levels and structure of these complex abilities need to be developed (Koeppen et al., 2014). Since in academic discourse, the linguistic definition of both terms does not facilitate a clear differentiation between *competence* and *competency*, for the sake of consistency in this study, the term *competence* is predominantly employed.

Many different models conceptualise ways how competence development can be integrated into educational processes (Weinert, 2001). From the perspective of educational sciences, the education system benefits significantly from learning and teaching approaches based on competence development as they increase overall efficacy as well as encourage us to consider the diversity of various contributing factors and their interrelatedness, which are vital for a learner to become successful in respective contexts (Vitello et al., 2021). This interrelatedness of factors and contexts in which the learner is embedded is of particular interest for this study, which follows a holistic and integrated relationship-based approach towards competence development (Gonczi & Athansaou, 2004, as cited in Guerrero & De los Ríos, 2012). This holistic or systems approach has been embraced in numerous prominent competence frameworks, such as the Model of Competences for Democratic Culture (Council of Europe, 2018), Transformative Competences of the Learning Compass 2030 (OECD, 2018), etc. The latter framework underlies the importance of education in equipping learners for the challenges in the increasingly volatile, uncertain, complex, and ambiguous world, as already referred to as a VUCA world (Bennis & Nanus, 2003).

Furthermore, as Brown (2020) points out, the most disruptive implications for education today are carried by artificial intelligence (AI), machine learning, big data, digital automation, connectivity of smart technologies, etc., which are often referred to as the *Fourth Industrial Revolution* – the revolution of technology and skills (The World Economic Forum, 2016). The increasing interconnectivity, complexity, and rapid change in what kind of knowledge and competences are necessary for daily life and employment are changing (The World Economic Forum, 2020), and the focus is shifted towards skills such as creativity, complex problem-solving, cooperation, flexibility, as well as the overall unpredictability of what learners may need to be able to do in the future (Markauskaite et al., 2022). This uncertainty arising from the complex nature of the internal relationships and interactions between phenomena and the environment encourages us to move away from the long-standing concepts of linearity, hierarchy, structure, and a top-down process of control to a more complex systems approach, characterised by non-linearity, adaptation, and emergence (Brown & Duignan, 2021). As major educational contexts keep moving beyond long-standing modernist attitudes

towards learning and teaching, the understanding of these new dynamics of education can benefit from complexity-informed understanding which is increasingly more apparent across many disciplines and professions (Byrne & Callaghan, 2014). Therefore, taking a holistic attitude and focusing on the interconnectedness of various factors that determine competence could provide suitable pathways to redefine the overall competence development. After all, competence can reasonably be viewed as a subject of complex system theories as it encompasses a variety of learners' internal factors, such as values, attitudes, knowledge, skills, etc. (Vitello et al., 2021).

Finally, lies the question of whether it is even possible to conceptualise competence development given the uncertainty and complexity of this unknown future and whether the perspective of complex systems theories can contribute to this topic. Which possible methodologies could enable educational researchers to explore competence as *emergence* (Davis & Sumara, 2008), competence as a part of a complex system (Vitello et al., 2021), or even competence as a complex system on its own (Jacobson, 2019)? Which models have been used for that? To address these questions, this study seeks to conduct a systematic literature review on competence and ways to model it from the perspective of complex systems theories. The next section of this paper introduces the theoretical background and reasons how and why complexity modelling methods can be used to address this issue.

Theoretical Background of Complex Systems

The variety of meanings ascribed to complexity is present in several diverse approaches in educational sciences and beyond, as "the claims that learning is complex says nothing that humanity has not known for thousands of years" (Davis & Sumara, 2010, p. 856). Therefore, this study follows Morin's (2007) distinction between *restricted complexity*, and *general complexity*, as this typology is based on different ways to respond to the complexity of various phenomena. In the paradigm of restricted complexity, complex problems are referred to as merely complicated; meanwhile, in the general complexity paradigm, "complexity is treated as an ontological fact, which holds certain epistemological and cognitive implications for how we deal with complexity" (Woerman et al., 2018, p. 3–4). The only way in which we can understand "complexity in all its complexity" is by modelling complex systems (Woerman, 2016). In other words, besides conceptual implications for theory building in education and learning, adopting a complex systems approach introduces novel methodological perspectives into educational research through innovative modelling methods (Jacobson, 2020). Conventional quantitative and qualitative methodologies are "limited to explaining what has already emerged" (Epstein & Axtell, 1996, as cited in Jacobson, 2020, p. 378); meanwhile, augmenting these methodologies with complexity modelling could serve in researching competence development for the uncertain future.

In addition, complex systems theories challenge the so-called representational epistemology (Osberg et al., 2008), suggesting that knowledge – as well as competence, in the case of this study – should not be treated as representations of the world but as inextricable parts of the continuous ever-evolving system known as reality. Therefore, to conceptualise competence in a VUCA world, we cannot merely rely on what competence is supposed to represent in the world because this representation is static and only temporal. Alternatively, based on temporal epistemology suggested by the complex systems approach, "there are no final solutions, only ongoing interactions" (Osberg et al., 2008, p. 215). Therefore, conceptualising knowledge and competence as either part of a larger complex system or a system of its own sheds light on the constant dynamics and temporality, which are key to defining competence development for an uncertain future.

Furthermore, an apparent ontological turn is underway in the current educational paradigm as the inextricability between *knowledge* and *knowing* in the post-modern sense insists upon a shift from what learners *develop* or *acquire* to who they *become* (Dall'Alba & Barnacle, 2007). This calls for an ontological turn, encouraging viewing students not as mere knowers but as persons (Barnett, 2004), is evoked by the uncertainty and instability of the aforementioned VUCA world, in which „changes that bear upon our sense of our own being [...] are, in sum, ontological challenges" (Barnett, 2004, p. 249). Hence, respectively, competence development can hardly be further conceptualised on the situations based in the past or present but rather in the unknown future, and complexity modelling methods are adept at addressing this aspect.

Methods

Planning the Review

A systematic review is an accurate and reliable tool for summarising relevant literature, as the procedures involved are carried out based on the review process protocol. The latter is aimed at minimising research bias and ensuring that the review process is transparent and accurate, and its findings can be replicated by other researchers working in similar contexts (Booth et al., 2021). In this study, the systematic review was undertaken in accordance with the reporting techniques of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocol (Page et al., 2020), as explained in the following.

To find publications which introduce complexity modelling approaches in competence development, the systematic review process was focused on the digital databases of Web of Science, EBSCO Host, and Scopus. It has been assumed that searching for publications in these highly recognised databases would optimise this search as they provide robust search engines and span publications of high-impact journals.

Search Terms and Eligibility Criteria

The search process in these databases included queries with search terms referring to both *competence* and *competency*, as there is an ongoing discussion on whether these two terms can be used synonymously, which is often the case. Therefore, both of the term options were included in the queries: the root *competenc* was used while the ending was replaced with an asterisk (*).

Another area for potential ambiguity was the usage of the search term *complexity*, which, on the one hand, is often interchangeably used for *complexity thinking* – a term coined by Davis and Summara (2008) to refer to complex systems theories, particularly in the context of educational sciences. On the other hand, complexity in education is also often used to describe various holistic approaches towards educational problems or the complicacy of educational processes. Therefore, a pilot search was carried out in the Web of Science database to compare the number of returns, which included *complexity* or *complexity thinking* (a total of 2,216), against returns where only *complex system** was used (a total of 186). To minimise the influx of studies that are unlikely to revolve around complex systems, it has been decided only to use the term *complex system**. There is a slight possibility that some of the authors might not have included the term *complex systems* and only used *complexity* or *complexity thinking*, and this has been taken into account as one of the limitations of this study.

Lastly, the term *model* is also crucial in this study; therefore, all the forms of this term (such as *models*, *modeling*, or *modelling*) have been included, replacing the ending with an asterisk (*).

The eligibility criteria were refined for the final sample to fully align with the research questions and its major aim. Whilst selecting the primary sources for the literature review, the following inclusion criteria were considered:

- Publications on competence development and complex systems models;
- Studies on competence development and complex systems approach;
- Studies on complex systems-informed approaches in teaching and learning that also refer to competence;
- Publications of peer-reviewed journals in Web of Science, EBSCO Host, and Scopus databases;
- Studies available online as open or full access;
- Published in English.

Exclusion criteria were defined as follows:

- Studies not focused on complexity modelling or complex systems-informed approach in the context of competence development or teaching and learning;
- Publications in languages other than English;
- Duplicates in any of the databases.

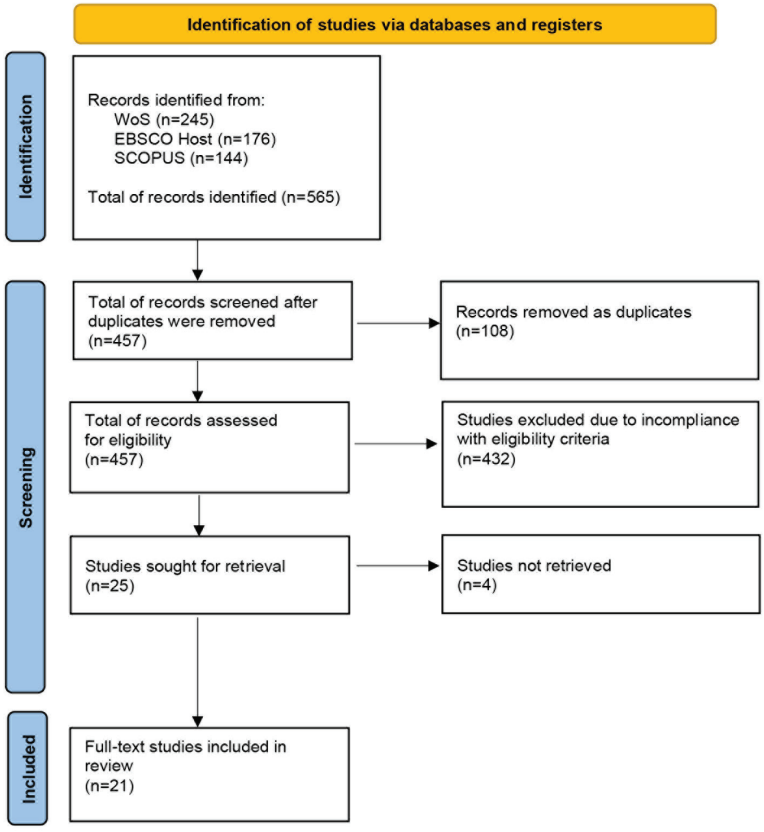
Search and Sample Selection

The search queries in the selected databases resulted in a total of 565 studies: Web of Science (245), EBSCO Host (176), and Scopus (144).

During the first iteration, the initial sample was reduced by removing the duplicate publications from other databases (a total of 108 studies were removed during the first iteration). During the second iteration, the titles and abstracts of the remaining 457 publications were analysed based on the eligibility criteria. All papers that did not apply complexity modelling as a method for researching competence development or studies which did not follow the complex systems-informed approach in the context of competence development or teaching and learning were excluded, as well as studies that could not be accessed in full form, resulting in the final sample of 21 studies. The summary of the sample selection process based on the PRISMA flow diagram (Page et al., 2020) is represented in Figure 1.

Figure 1

Systematic Review Process Based on the PRISMA Flow Diagram (adapted from Page et al., 2021)



Limitations

The major limitations of this study are related to the selection of search terms. Firstly, as mentioned before, the decision to use only the term *complex system** in the search queries and exclude the terms *complexity* or *complexity thinking* leaves a possibility that some authors have carried out studies in complexity modelling without referring to the term *complex systems.* Secondly, including search terms such as *skill, capability, literacy*, and similar terms would have encompassed a much broader spectrum of literature. However, the scope of this study was intended to focus on the specific conceptualisation of competence as promoted in EU documents and higher education systems across EU countries. Thus, this literature review examines the wide range of meanings associated with competence and explores how the concept, specifically the term *competence*, is conceptualised within various educational contexts in the studies included in this systematic review.

Reporting Findings

Upon reviewing the designated literature, all collected data was organised in a single data sheet. The examination of the chosen studies was structured according to the initial research questions posited within this investigation. Subsequently, multiple categories were deducted, including: (1) competences examined in the reviewed literature, (2) complex systems determined within the reviewed literature, and (3) developed or assimilated modelling approaches adopted in the reviewed studies. Following these categories, content analysis utilising MaxQDA Analytics Pro 23 software (version 2023.4.0) was employed to systematically encode the information retrieved from selected articles.

Results and Discussion

Sample Overview

The scope of the reviewed studies spans various domains, encompassing social science, medicine, engineering, computer science, and information technologies. Nevertheless, the primary domain where the adoption of complex systems approach and competence modelling is prominent lies within finance, particularly business administration, management, and related fields (n = 6).

In addition, during the preliminary exploration conducted on the Web of Science database, it was observed that the predominant concentration of studies occurred within the timeframe spanning from 2000 to 2023. This observation was subsequently supported by searches in other databases as well, albeit with several instances of studies conducted prior to this period. Therefore, to maintain methodological consistency, it

was deemed appropriate to confine the search parameters to the period of 2000 to 2023 across all databases, as the bulk of studies on competence modelling from a complex systems point of view were conducted within this specified timeframe.

Diversity of Competences and Research Domains

A diverse array of competences has surfaced in this systematic review. These competences range from general skills, such as *core* and *accidental competencies*, to highly subject-specific competences, such as *financial risk management* or *game facilitation*. Notably, both terms, *competence* and *competency*, have been utilised interchangeably across the analysed studies; however, as previously indicated for the sake of consistency within this article the term *competence* is predominantly employed, except when referencing the original studies directly.

Table 1 comprehensively summarises all the competences examined in the systematically reviewed literature. As indicated in the table, there is no major differentiation between subject-specific and generic competences, or transferable skills, which can be further grouped as interpersonal, systemic, and instrumental competences (Wagenaar, 2014), throughout the reviewed studies, and their distribution in various research domains appears relatively balanced.

Table 1

List of Competences Identified in the Systematic Review

Field	Subject-specific	Generic
Finance	Business administration skills and competencies	Core competences
	Entrepreneurial competencies	
	Financial core competencies	Risk management competency
	Big Data-related competencies	
Computer Science and IT	Game facilitation competency	Innovative and entrepreneurial competencies
	Professional IT competencies	Interpersonal competences
Education	Teachers' competence to develop students' information literacy (TCDSIL)	Intercultural communicative competence (ICC)
		Teaching competency
		Psychological competencies
Engineering	Engineer's professional competencies	Accidental competencies
	Chemical engineering competences (eco-design and transversal)	
Sociology		Citizenship competences
Medicine		Continuous professional development-related competencies

The primary focus of this systematic literature review lies in examining the conceptualisation of competence from the perspective of complex systems theory. While the degree of reliance on complex systems theories across the reviewed articles varies, several discernible trends have emerged.

Firstly, several studies (Blažinić et al., 2020; Kovaliuk et al., 2019; Kravtsov & Kobets, 2018) emphasise competence at the individual level, viewing it as a trait exhibited by the individual. In such instances, attention is directed towards the internal relationships among the elements comprising a particular competence. In these studies, competence is characterised, for example, as a *dynamic combination of cognitive and metacognitive skills*, *knowledge and comprehension*, *interpersonal and practical abilities*, and *ethical values* (Blažinić et al., 2020), or as the *capability to fulfil industry demands within the contexts of knowledge*, *skills, experience, and personal qualities* (Kovaliuk et al., 2019). At this individual level, competence serves as a mechanism through which professionals in a given field can leverage their knowledge, skills, and attitudes to effectively accomplish assigned tasks (Kravtsov & Kobets, 2018).

Secondly, the following studies delineate competence through a functionalist lens, wherein, for example, the focus lies on the effects engendered by competence (Drejer, 2000). Neely and Tucker (2013) define competence as the *requirements for college graduates to secure employment* in their field of study, while Bonjour et al. (2002) emphasise the connection between competence and completed action, for example, achieving a particular goal, executing a task, fulfilling a mission, etc. Campbell and Parboosingh (2013) note that practitioners themselves have defined competences "as something deemed relevant to their personal practice needs" (p. 37).

Another pertinent perspective on defining competence involves a more contextual approach, whereby competence is not conceptualised as an individual attribute but rather a characteristic of a larger system. For instance, citizenship competences are viewed as attributes of social systems (Avila-Garzon et al., 2022), teaching proficiency of college teachers is considered a crucial metric for assessing the overall strength of the institution (Chen & Yang, 2020), and financial core competence is regarded as integral to the corporation's developmental process (Chen, 2009). In one study, competence was described as possessing a dual nature, meaning it can be either inherent or situational (Strugielska and Piątkowska, 2017). In addition, at least six studies have conceptualised competence as a complex system in its own right, a discussion of which is presented in a subsequent section of this article after the general overview of complex systems is discussed.

Finally, certain studies (Walther et al., 2011; Rogers et al., 2013) characterise competence as an emergent outcome or consequence of a specific system's behaviour. To illustrate this, Walther et al. (2011) assert that, in engineering education, the process of learning and evolving into a professional engineer *emerges* from a multitude of influences outside the realm of explicit instruction. Similarly, Rogers et al. (2013) observe that

competence begins to *emerge* as students' confidence and knowledge expand through recurrent exposure and facilitation.

Complex Systems: From Classrooms to Social-Ecological Systems

One of the major objectives of this systematic literature review was to determine how various studies on competence development employ a complex systems approach and define complex systems. The reviewed studies introduced various interpretations of the notion of a complex system. In addition, in the reviewed literature, a visible trend emerged – complex systems are often traced back to the educational domain. For example, a complex system was conceptualised as a *classroom*, *competence*, *assessment* of competence, *education*, educational *processes*, curriculum *revision*, *knowledge system*, *maintenance of certification*, etc. In other cases, the notion of complex systems was more characteristic of the researched domain, for example, computer science (complex system as a *computer game*, emerging *technologies*), social science (social-ecological *system*, *society*), and finance (business *system*, *network* of risk management and supply).

It is essential to acknowledge that for a system to be regarded as a complex system specific properties must be present, such as emergence, interaction between system components, unpredictability, heterogeneity, chaos, nonlinearity, feedback loops, etc (Snyder et al., 2011). In certain instances, the reviewed studies did not provide thorough explanations as to why a particular entity was defined as a complex system. Some studies (Wu et al., 2022; Neely & Tucker, 2013; Kortman & Peters, 2021) only briefly stated that a particular entity is a complex system without any further explication.

However, three studies offered explicit insights into the constituents of a complex system. Iordan et al. (2008) identified a knowledge system as a complex system, focusing on the development of a multi-agent model and its application in describing competences. Rogers et al. (2013) sought to construct a framework for learning within a complex system, examining participative planning and adaptive decision-making in complex social-ecological systems characterised by "nonlinear, context-, and contingency-specific interactions among emergent entities" (p. 30). Lastly, Avila-Garzon et al. (2022) aimed to highlight the dynamics of complex social systems and the mechanisms which individuals employ to resolve conflicts and identify strategies that can aid citizenship education within these complex social systems.

Competence as a Complex System

The research revealed five studies that referred to competence or competency as a complex system. The overview of these findings is presented in Table 2.

Table 2

Studies Conceptualising Competence as a Complex System

Definition of competence	Approaches adopted	Ways to develop competence	Additional comments	Reference
A collective structure, which could be managed at different levels: that of an individual actor, collective actor, and enterprise level.	Action theory and a systemic approach	Competence respectively can be developed at the individual, collective, and enterprise levels. The study focuses on the first two levels and follows the accepted definition of competence as putting into practice the theoretical knowledge, know-how, and know-who – the attitudes and behaviour.	The overall notions of competence management and knowledge management are troublesome, because either the relation between knowledge and competency is under-discussed, or the concept of competence has been poorly modelled.	Bonjour et al. (2002)
Competence is a complex adaptive system typical features of which include owning subsystems, openness and unbalance, and nonlinear action.	School of thought promoted by Santa Fe Institute (SFI)	Two underlying sides which govern the whole evolution of the financial core competence system: (1) each subject's own evolution and stimulus, and (2) action and reaction between the entire system and environment.	The analysis of the constituent elements of financial core competence to reveal the evolution of it as a complex system development process allows more accurate insights into the future development of the system.	Chen (2009)
Competence is a cross-functional processes with a large number of people and technologies; it is a continuous system rather than a stable entity which can be identified once and for all.	Organisational learning	The key to understand how competences develop is learning of individuals as a group. The formal and informal way in which human beings interact is an essential constituent of a competence.	Competence on the organisational level should be treated as a system, instead of focusing solely on its individual elements, and what should be analysed is the interplay of these elements.	Drejer (2009)

Competence is a dynamic combination of cognitive and metacognitive abilities, knowledge and understanding, practical and interpersonal capabilities, and ethical dispositions whole multitude of which and the activities between constitute a complex system.	Systems theory	*unspecified*	The study provides a conceptual model of interpersonal competences, their causes, and their respective sub-causes, which serve as the basis for a computational systems dynamics model. This kind of a model aims to develop computer simulations of interpersonal competence as a complex system to build more effective policies and organisations.	Blažinić et al. (2020)
Competence is a two-level phenomenon and can be defined based not only the individual characteristics but also a variety of organisation-level factors.	Hierarchical linear modelling	Competence can be developed by receiving support and guidance from others (ex., teachers).	The authors of this study were not specific in explaining why they regard teachers' competence to develop students' information literacy (TCDSIL) as a complex system and what complex system properties this competence possesses.	Wu et al. (2022)

Theoretical and Computational Competence Modelling

Lastly, models or modelling methods employed in the reviewed studies were intricately linked to the overarching research objectives of each study and aligned with their respective aims, such as:

- explore competence assessment;
- improve competence research (such as better data collection and more accurate results);
- identify competence variables, factors, and/or their management;
- identify sub-competences of a particular competence;
- find ways to foster a particular competence;
- assess the importance of a particular competence for a broader context;
- explore the process of competence development and/or change, etc.

Several studies specifically focused on the epistemological foundations of complex systems theories and aimed to:

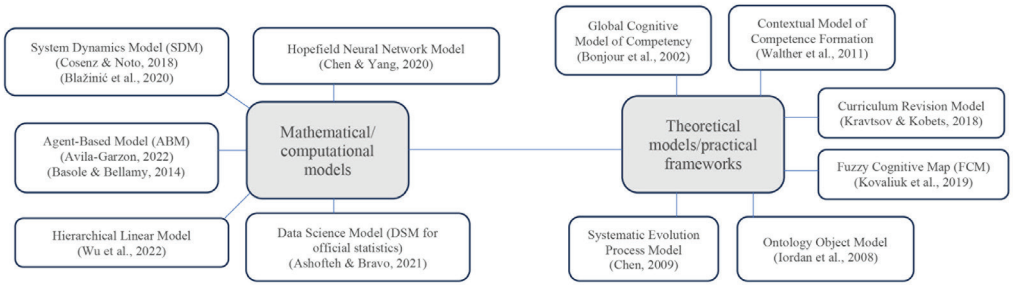
- provide a framework for how learning takes place in a complex system (Rogers et al., 2013; Kovaliuk et al., 2019);

- ascertain whether a particular competence is a complex system (Wu et al., 2022);
- validate the perspective of complex systems for developing a particular competence (Chen, 2009).

A number of the reviewed studies relied on theoretical models or practical frameworks, the most of which adopted a complex systems point of view. In contrast, one-third of the analysed studies have set the objective to develop a certain mathematical and/or computational model to achieve the aforementioned aims. The overview of the models adopted in the reviewed literature is presented in Figure 2.

Figure 2

Models and Modelling Approaches Adopted in the Reviewed Literature



The rest of the studies (Drejer, 2000; Neely & Tucker, 2013; Rogers et al., 2013; Campbell & Parboosingh, 2013; Strugielska & Piątkowska, 2017; Pokrovskaia et al., 2018; Margallo et al., 2019; Kortman & Peters, 2021) did not adopt or develop any particular model; however, they relied on the combination of complex systems theories and/or various modelling approaches.

Conclusions

Complex systems research is garnering attention among educational researchers due to its potential to provide valuable epistemological and methodological insights for addressing the challenges posed by the VUCA world. Within the context often referred to as the era of the Fourth Industrial Revolution – characterised by rapid technological advancements and evolving skills requirements – the concept of competence has become increasingly elusive, with a growing array of diverse factors influencing it being taken into account. The primary objective of this systematic review was to elucidate how the notion of competence is conceptualised through the lens of complex systems theories and to identify the modelling methods employed by researchers in existing studies.

Firstly, the systematic literature review revealed various complexity-informed conceptualisations of competence. To begin with, competence was often conceptualised as a property inherent to the individual, emphasising its internal complexity, including the intricate nature of its components and their interrelationships. While not all studies categorised competence as a complex system, a substantial number presumed precisely that. Some studies (Drejer, 2000; Neely & Tucker, 2013; Bonjour et al., 2002; Campbell & Parboosingh, 2013) underscored a functionalist approach to the definition of competence, emphasising the connection between competence and a completed task or a mission. Secondly, a contextual approach emerged, portraying competence as a characteristic of a larger system, such as a teaching institution, business company, or social system. In these studies, attention was directed towards competence as an integral part of the broader context, its relationships within this context, and its role therein. Lastly, in some instances, competence was regarded as an emergent phenomenon, aligning with the concept of emergence, which is central to complex systems theories, used to categorise the rise of new properties out of the interactions taking place inside the system within its parts and the environment (Crutchfield, 1994).

The second research question raised in this study was aimed at identifying particular complex systems in the reviewed literature. The delineation of complex systems across reviewed literature varied, but in the majority of cases, it was associated with learning and knowledge building: complex system as a *classroom*, *education* or the *educational process*, *competence* or *competence assessment*, *curriculum revision process*, etc. In other instances, complex systems were more directly linked to specific research domains, such as *social-ecological systems* or *society* in sociology, *business systems* or *risk management and supply system*s in finance, or *computer games* or *emerging technologies* in computer science. While some studies (Wu et al., 2022; Neely & Tucker, 2013; Kortman & Peters, 2021) did not explicitly articulate the rationale for treating their identified systems as complex, recognising that not all intricate phenomena qualify as complex systems, others delved deeper into elucidating the non-linear and context-bound interactions occurring within the identified complex systems, along with their internal dynamics. This underscores the evolving nature of applying a complex systems approach in the social sciences, highlighting the need for a more robust theoretical and methodological understanding of its conceptualisation.

Thirdly, five of the reviewed studies referred to competence as a complex system (Bonjour et al., 2002; Chen, 2009; Drejer, 2009; Blažinić et al., 2020; Wu et al., 2022). Authors delineated competence as *a collective structure, a self-organising complex adaptable system*, *a continuous system, a multitude of entities, a two-level phenomenon*, etc. These varied conceptualisations underscored the multidimensionality of competence when viewed through the lens of complex systems. For instance, there was emphasis placed on the temporal dimension, highlighting competence as an inherently dynamic and continually evolving subject to the individual evolution of each participant within

the system. Other studies underscored the interplay between the entire system and its environment, positing that a crucial aspect of understanding competence development lies in comprehending how individuals learn collectively as a group.

Lastly, the study identified various modelling approaches in existing competence research literature. While not all studies under review developed a specific model, the majority referred to a particular modelling approach. This choice was contingent upon the aim of each study. Several studies (Basole & Bellamy, 2014; Cosenz & Noto, 2018; Blažinić et al., 2020; Chen & Yang, 2020; Ashofteh & Bravo, 2021; Avila-Garzon, 2022; Wu et al., 2022) aimed to develop or adopt specific mathematical and/or computational models, such as the system dynamics model (n = 2), agent-based model (n = 2), neural network model (n = 1), data science model (n = 1), and hierarchical linear model (n =1). While the latter two models are not inherently complex systems models, their utilisation in the reviewed studies was justified by the respective study's intention to elucidate the intricate relations or systems behaviour related to competence development. Additionally, various theoretical models were employed, including a global cognitive model of competence designed to comprehend the functionality of a complex system, a fuzzy cognitive map utilised to model competence development and explore the diverse factors influencing it, a curriculum revision model, a systematic evolution process model, an ontology object model, and a contextual model of competence formation. The latter aimed to illustrate the intricate and emergent socio-cognitive processes contributing to the so-called professional formation of students. Studies that did not adopt or develop a particular model relied on a combination of a complexity-informed approach and modelling as a methodological means to research competence development.

After all, what implications does complexity-informed conceptualisation of competence – for example as a complex system or emergence – have for the overall competence development? Can complexity-informed competence modelling help redefine competence in a VUCA world? On the one hand, this is a potential avenue for future research in this domain. On the other, the systematic literature concludes that competence development can be characterised as a non-linear, self-organising, dynamic, and adaptable system, rather than a linear and reductionist process. It emerges as a collective outcome of individuals learning together within groups, intricately linked to the constantly evolving environmental factors. In social sciences, complexity modelling offers a methodology to capture the inner dynamics of competence as a system, acknowledging its non-static nature and its interconnectedness within a larger context. Drawing on simulations generated by these complex systems or respective models, it becomes feasible to empirically substantiate the holistic approach towards competence development upheld by competence frameworks highlighted at the outset of this study.

This study aimed to elucidate how competence is conceptualised and modelled from the perspective of complex systems theories. Consequently, educational researchers and practitioners exploring competence modelling could derive valuable insights

from this systematic review, gaining a deeper understanding of complexity-informed concepts of competence and competence models, which, in turn, provides new angles for future educational research.

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Kompetencijų modeliavimas kompleksinių sistemų požiūriu: sisteminė literatūros apžvalga

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Santrauka

Šiame straipsnyje siekiama išsiaiškinti, kaip šiuolaikiniame pasaulyje, kuris yra nepastovus, neapibrėžiamas, kompleksiškas ir įvairiaprasmis (angl. *VUCA world*), įvairios kompetencijos gali būti konceptualizuojamos ir modeliuojamos iš kompleksinių sistemų teorijų perspektyvos. Nors visuotinai pripažįstama kompetencijų ir jomis grįsto mokymo svarba, tačiau šiandieniniame nuolat kintančiame ir ateities neapibrėžtumo sąlygojamame pasaulyje kompetencijų samprata kinta. Šiuo tyrimu tikimasi išsiaiškinti, kuo kompleksinių sistemų požiūris, kuris vis dažniau taikomas ugdymo mokslų tyrimuose, gali būti vertingas kompetencijos sampratai tirti. Straipsnyje pateikiama sisteminė įvairiose duomenų bazėse 2000–2023 metais publikuotų straipsnių (N = 21) apžvalga atskleidžia, kaip, kompleksinių

sistemų požiūriu, kompetencijos gali būti konceptualizuojamos tiek individualiu, tiek visos sistemos ar organizacijos lygmeniu, laikantis funkcionalistinio arba kontekstualaus požiūrio. Apžvelgus tyrimus galima daryti prielaidą, kad tam tikrais atvejais kompetencija gali būti traktuojama kaip emergentinis reiškinys (angl. *emergence*) ar netgi savarankiška kompleksinė sistema, pasižyminti kompleksinėms sistemoms būdingomis savybėmis: nelinijiškumu, nepastovumu, emergentiškumu, grįžtamojo ryšio kilpomis ir pan. Galiausiai straipsnyje apžvelgiami įvairūs kompetencijų tyrimuose naudojami modeliai, kurių taikymas atveria naujus kompetencijų ugdymo ir apskritai edukologijos tyrimų kelius.

Esminiai žodžiai: *kompleksinės sistemos, kompetencija, kompetencijos modelis, modeliavimas, sisteminė literatūros apžvalga.*

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