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Liliia O. Fadieieva

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DISSERTATION

METHODOLOGY OF USING INFORMATION AND COGNITIVE TECHNOLOGIES OF ADAPTIVE LEARNING OF PEDAGOGICAL UNIVERSITIES STUDENTS

011 Education and Pedagogical Sciences

01 Education / Pedagogy

Submitted in Fullfilment of the Scientific Degree of Doctor of Philosophy

Dissertation contains the results of own research. All ideas, results, and texts of other authors have references to the relevant sources.

L. O. Fadieieva

Scientific supervisor **Serhiy O. Semerikov**, Doctor of Educational Sciences, Professor, Senior Researcher

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ABSTRACT

Фадєєва Л. О. Методика використання інформаційно-когнітивних технологій адаптивного навчання студентів педагогічних університетів. – Кваліфікаційна наукова праця на правах рукопису.

Дисертація на здобуття наукового ступеня доктора філософії за спеціальністю 011 Освітні, педагогічні науки. – Криворізький державний педагогічний університет, Кривий Ріг, 2024.

Інформаційно-когнітивні технології, такі як штучний інтелект, людино-машинна взаємодія, когнітивні обчислення, візуалізація інформації та управління знаннями, спрямовані на розробку систем, інструментів та інтерфейсів, які безшовно інтегруються з когнітивними процесами людини та доповнюють їх. Інформаційно-когнітивні технології відіграють дедалі важливішу роль в освіті, уможливлюючи персоналізоване навчання та покращуючи набуття знань.

Такі інформаційно-когнітивні технології в освіті, як адаптивне навчання (яскравий приклад застосування штучного інтелекту в освіті для підтримки персоналізованого навчання), мають потенціал для покращення освіти через персоналізоване навчання. Аналіз великих освітніх даних, що генеруються у процесі використання систем управління навчанням, таких як Moodle, надає можливість виявлення закономірностей, ідей та тенденцій, що дозволять викладачам та адміністраторам приймати рішення на основі даних.

Дослідження присвячене використанню системи управління навчанням (LMS) Moodle та її потенціалу для впровадження адаптивного навчання в педагогічних університетах. Використовуючи багатогранний підхід, який поєднує бібліометричний аналіз, моделювання структурних рівнянь та емпіричні дані з Криворізького державного педагогічного університету, дослідження забезпечує

глибоке розуміння тематичних кластерів у рамках дослідження адаптивного навчання, взаємозв'язку інструментів Moodle, їхнього впливу на результати навчання студентів та надає рекомендації із упровадження ефективних стратегій адаптивного навчання.

Завдяки бібліометричному огляду визначені п'ять основних тематичних кластерів, які характеризують дослідження із адаптивного навчання у вищій освіті: (1) загальні концепції адаптивного навчання в системах електронного навчання, (2) освітні технології, (3) адаптивні системи навчання та педагогічна інформатика, (4) навчання та дослідження в галузі освіти та (5) персоналізоване навчання. Аналіз показав, що ці кластери тісно взаємопов'язані, відображаючи багатовимірну та динамічну природу досліджень адаптивного навчання. Досягнення або відкриття в одному кластері можуть мати наслідки та сприяти розвитку в інших кластерах, підкреслюючи міждисциплінарний характер цієї галузі. Зокрема, аналіз підкреслив ключову роль технологій штучного інтелекту в розробці адаптивних систем навчання, а також важливість персоналізованої освіти та урахування індивідуальних стилів навчання.

Щоб дослідити взаємозв'язок ресурсів і діяльності Moodle, а також їхній вплив на результати навчання студентів, було застосовано кількісний підхід – моделювання структурних рівнянь (SEM-PLS). Використовуючи дані Криворізького державного педагогічного університету, було розроблено концептуальну модель, засновану на соціально-конструкційній педагогіці, покладеної в основі розробки Moodle, і положеннях університету щодо структури курсу та оцінювання Moodle. Модель складалася з п'яти конструктів: "Інформація", "Ресурси", "Діяльність", "Комунікація" та "Оцінка". Конструкти "Інформація", "Ресурси", "Діяльність" і "Комунікація" були початковими конструктами, сформованими з використанням індикаторів, які були безпосередньо з даних Moodle, тоді як конструкт "Оцінка" по відношенню до них був прихованим конструкктом, що відображав дані про успішність студентів, узяті із заліково-екзаменаційних відомостей.

Результати моделювання надали можливість зробити декілька ключових висновків. По-перше, існує сильний позитивний зв'язок між конструктом "Діяльність" (інтерактивні навчальні елементи, такі як SCORM, вибір, завдання, тести) та конструктом "Комунікація", що свідчить про те, що збільшення використання інтерактивних елементів у курсів Moodle пов'язане з вищим рівнем спілкування та взаємодії студентів і викладачів. По-друге, спостерігався помірний позитивний зв'язок між конструктом "Ресурси" (URL-адреси, сторінки, мітки тощо) і конструктом "Діяльність", що вказує на те, що доступність і різноманітність ресурсів у межах курсу Moodle пов'язані з включенням різноманітних навчальних дій. По-третє, було виявлено помірний позитивний зв'язок між конструктом "Інформація" (опис курсу, програма, вступ) і конструктом "Оцінка" (оцінки студента), що свідчить про те, що добре розроблені та інформативні матеріали курсу пов'язані з кращими результатами оцінювання студентів.

Цікаво, що дослідження не знайшло доказів значного прямого зв'язку між комунікацією чи діяльністю та конструктом "Оцінка". Незважаючи на те, що це важливі компоненти, їхній вплив на результати оцінювання є більш складним і на нього впливають інші фактори.

Головним висновком цього дослідження є те, що просте використання засобів Moodle не гарантує впровадження адаптивного навчання для студентів педагогічних університетів. У той час як Moodle надає інструменти та функції, які потенційно можуть підтримувати адаптивне навчання, такі як персоналізовані навчальні траєкторії, адаптивне надання контенту та навчальна аналітика, наявність і використання цих інструментів самі по собі не гарантують ефективного впровадження адаптивного навчання. Щоб по-справжньому використати потенціал адаптивного навчання, викладачі та розробники курсів повинні застосувати продуманий і стратегічний підхід, який передбачає ретельне навчальне проєктування, інтеграцію відповідних педагогічних стратегій і використання адаптивних можливостей Moodle у відповідності до конкретних цілей навчання та потреб студентів.

Наукова новизна результатів дослідження полягає в наступному:

1. Бібліометричний аналіз джерел з проблеми дослідження надав можливість визначити ключові тематичні кластери та тенденції, виявивши багатовимірний та взаємопов’язаний характер досліджень у галузі адаптивного навчання.
2. Розробка та застосування кількісної моделі SEM-PLS для дослідження зв’язків між різними ресурсами Moodle LMS, діяльністю та результатами оцінювання студентів надала уявлення про взаємозв’язок різних інструментів Moodle, які використовують викладачі в педагогічних університетах.
3. Існують емпіричні докази впливу різних інструментів Moodle на результати навчання студентів, зокрема сильний позитивний зв’язок між інтерактивною діяльністю та спілкуванням/залученням, помірний позитивний зв’язок між ресурсами та навчальною діяльністю, а також помірний позитивний зв’язок між інформацією про курс і результатами оцінювання.
4. Висновок про те, що просте використання інструментів Moodle не гарантує впровадження адаптивного навчання для студентів педагогічних університетів, підкреслює необхідність ретельного проєктування навчання, інтеграції відповідних педагогічних стратегій і педагогічно виваженого використа-

ння адаптивних можливостей Moodle.

Практичне значення отриманих результатів полягає в наданні рекомендацій для викладачів і розробників курсів щодо оптимізації використання Moodle LMS шляхом акцентування уваги на інтерактивних заходах, різноманітних ресурсах, вичерпній інформації про курси та стратегічній інтеграції адаптивних можливостей Moodle для підвищення взаємодії студентів, спілкування та результати навчання в педагогічних університетах.

Ключові слова: інформаційно-когнітивні технології, адаптивне навчання, системи управління навчанням, Moodle, педагогічні університети, результати навчання студентів, інтерактивна діяльність, навчальні ресурси, навчальна аналітика, персоналізоване навчання, освітня технологія, моделювання структурними рівняннями, бібліометричний аналіз, взаємозв'язок інструментів, дизайн курсу, спілкування, оцінка, продуктивність, методика використання інформаційно-когнітивних технологій адаптивного навчання студентів педагогічних університетів.

Fadieieva L. O. Methodology of using information and cognitive technologies of adaptive learning of pedagogical universities students. – Qualifying scientific work on manuscript rights.

Dissertation for the Doctor of Philosophy degree in the speciality 011 Education and Pedagogical Sciences. – Kryvyi Rih State Pedagogical University, Kryvyi Rih, 2024.

Information and cognitive technologies, such as AI, human-computer interaction, cognitive computing, information visualisation, and knowledge management, aim to design systems, tools, and interfaces that seamlessly integrate with and complement human cognitive processes. These technologies are increasingly important in education, enabling personalised instruction and improved knowledge acquisition and retention.

Information and cognitive technologies in education, like adaptive learning (a prominent application of AI in education, supporting personalised and effective learning experiences), can revolutionise education by providing more personalised, engaging, and effective learning experiences. By analysing large educational datasets produced by learning management systems (LMS) like Moodle, we can uncover patterns, insights, and trends, enabling data-driven decision-making for educators and administrators.

This comprehensive research delves into the use of Moodle tools and their potential for implementing adaptive learning in pedagogical universities. By employing a multifaceted approach that combines bibliometric analysis, structural equation modelling, and empirical data from the Kryvyi Rih State Pedagogical University, the study provides in-depth insights into the thematic clusters within adaptive learning research, the interconnectedness of Moodle tools, their influence on student learning outcomes, and the critical requirements for implementing effective adaptive learning strategies.

Through a rigorous bibliometric review, the study identified five main thematic clusters that characterise the landscape of adaptive learning research in higher education: (1) general concepts of adaptive learning in e-learning systems, (2) educational technology, (3) adaptive learning systems and education computing, (4) learning and education research, and (5) personalised learning. The analysis revealed that these clusters are closely interconnected, reflecting adaptive learning research's multidimensional and dynamic nature. Advancements or findings in one cluster can have implications and contribute to developments in other clusters, underscoring the interdisciplinary nature of this field. Specifically, the analysis highlighted the pivotal role of AI technologies in developing adaptive learning systems and the significance of personalised education and catering to individual learning styles. Additionally, various approaches within adaptive learning systems were emphasised, such as their development, implementation, and effectiveness evaluation.

To investigate the interconnectedness of Moodle resources and activities and their influence on student learning outcomes, the study employed a quantitative structural equation modelling (SEM-PLS) approach. Utilising data from Kryvyi Rih State Pedagogical University (KSPU), a conceptual model was developed based on the social constructionist pedagogy underlying Moodle's development and the university's regulations regarding Moodle's course structure and assessment. The model comprised five constructs: Information, Resources, Activities, Communication, and Assessment. The Information, Resources, Activities, and Communication constructs were emergent constructs formed using indicators directly observed from Moodle course data. In contrast, the Assessment construct was a latent construct reflecting student performance data.

The modelling results revealed several key findings. First, there was a strong positive relationship between the Activities construct (interactive learning activities like SCORM, choices, assignments, and quizzes) and the Communication construct, suggesting that increased utilisation of interactive activities within Moodle courses is associated with higher levels of communication and engagement among learners and instructors. Second, a moderate positive relationship was observed between the Resources construct (URLs, pages, labels, etc.) and the Activities construct, indicating that the availability and variety of resources within a Moodle course are linked to the inclusion of diverse learning activities. Third, a moderate positive relationship was found between the Information construct (course description, syllabus, introduction) and the Assessment construct (student grades), implying that well-designed and informative course materials are associated with better student performance on assessments.

Interestingly, the study did not find evidence of a significant direct relationship between Communication or Activities and the Assessment construct. While these are essential components, their impact on assessment performance appears more complex and influenced by other factors.

A notable conclusion from this research is that the mere use of Moodle tools does not guarantee the implementation of adaptive learning for students of pedagogical universities. While Moodle provides tools and features that could potentially support adaptive learning, such as personalised learning paths, adaptive content delivery, and learning analytics, the presence and use of these tools alone do not ensure the effective implementation of adaptive learning. To truly leverage the potential of adaptive learning, instructors and course designers must employ a deliberate and strategic approach that involves careful instructional design, integrating appropriate pedagogical strategies, and using Moodle's adaptive capabilities in alignment with specific learning objectives and student needs.

The scientific novelty of the research results lies in the comprehensive examination of adaptive learning in higher education through bibliometric analysis, the development and application of a quantitative model to analyse Moodle tools' interconnectedness and their impact on learning outcomes, and the insights into the specific methodology conditions and considerations required for effectively implementing adaptive learning of pedagogical universities students using Moodle tools:

1. A bibliometric analysis identified key thematic clusters and trends in adaptive learning literature, revealing the research's multidimensional and interconnected nature.
2. Development and application of a quantitative SEM-PLS model to investigate the relationships between various Moodle LMS resources, activities, and student assessment outcomes, providing insights into the interconnectedness of different Moodle tools used by teachers in pedagogical universities.

3. There is empirical evidence on the influence of different Moodle tools on student learning outcomes, specifically the strong positive relationship between interactive activities and communication/engagement, the moderate positive relationship between resources and learning activities, and the moderate positive relationship between course information and assessment performance.
4. The finding that the mere use of Moodle tools does not guarantee the implementation of adaptive learning for students of pedagogical universities highlights the need for careful instructional design, integration of appropriate pedagogical strategies, and strategic use of Moodle's adaptive capabilities.

The obtained results are practical because they provide methodology guidance for instructors and course designers to optimise their use of Moodle LMS by emphasising interactive activities, diverse resources, comprehensive course information, and strategic integration of Moodle's adaptive capabilities to enhance student engagement, communication, and learning outcomes in pedagogical universities.

Keywords: information and cognitive technologies, adaptive learning, learning management systems, Moodle, pedagogical universities, student learning outcomes, interactive activities, learning resources, learning analytics, personalised learning, educational technology, structural equation modelling, bibliometric analysis, tools interconnectedness, course design, communication, assessment, performance, methodology of using information and cognitive technologies of adaptive learning of pedagogical university students.

List of publications

Scientific works in which the main scientific results of the dissertation are published

1. Fadieieva, L.O., 2021. Enhancing adaptive learning with Moodle's machine learning. *Educational Dimension*, 5, p.1–7. URL https://doi.org/10.31812/ed.625. **(article**

in the journal included in the list of specialized scientific publications of Ukraine)

2. Fadieieva, L.O., 2023. Adaptive learning: a cluster-based literature review (2011-2022). *Educational Technology Quarterly*, 2023(3), p.319–366. URL https://doi.org/10.55056/etq.613. **(article in the journal included in the list of specialized scientific publications of Ukraine)**
3. Fadieieva, L.O., 2023. Adaptive learning concept selection: a bibliometric review of scholarly literature from 2011 to 2019. *Educational Dimension*, 9, p.136–148. URL https://doi.org/10.31812/ed.643. **(article in the journal included in the list of specialized scientific publications of Ukraine)**

Scientific works certifying the scientific results of the dissertation

4. Fadieieva, L.O., 2023. Bibliometric Analysis of Adaptive Learning Literature from 2011-2019: Identifying Primary Concepts and Keyword Clusters. In: G. Antoniou, V. Ermolayev, V. Kobets, V. Liubchenko, H.C. Mayr, A. Spivakovsky, V. Yakovyna and G. Zholtkevych, eds. *Information and Communication Technologies in Education, Research, and Industrial Applications.* Cham: Springer Nature Switzerland, Communications in Computer and Information Science, pp.215–226. URL https://doi.org/10.1007/978-3-031-48325-7_16. **(article in the foreign scientific publication indexed by Scopus)**

Scientific works that additionally reflect the scientific results of the dissertation

5. Fadieieva, L. and Semerikov, S., 2024. KSPU Moodle activities and marks 2020-2022. URL https://doi.org/10.5281/zenodo.10938019. **(dataset)**

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INTRODUCTION

Actuality. Law of Ukraine "On Education" defines education as the fundament of the intellectual, moral, physical and cultural development of an individual, their successful socialisation, economic well-being, and a guarantee of development of the society and the state. Education is aimed, e.g., at the comprehensive development of a human being as a personality and as the supreme value of society, raising responsible citizens capable of making a conscious social choice and channelling their activities for the good of other people and society, and enriching the intellectual, economic, creative, cultural potential of the Ukrainian people on this basis, upgrading an educational level to ensure Ukraine's sustainable development and its European choice [206].

The primary provider of systematic quality education is competent teaching staff (educational – academic and research – worker). In the Strategy of higher education development in Ukraine for 2022–2032, it is indicated that "... professions related to health care, education, creativity, provision of individual services will remain relevant, as they cannot be replaced by automated systems even with the use of artificial intelligence" [20].

One of the purposes of higher education is to "ensure high-quality educational and scientific activity, competitive higher education, which is accessible to different segments of the population" [20]. Achieving this purpose involves "providing ... special support in access to higher education [through] equipping ... laboratories ... [at the] institutions of higher education with equipment for information technologies (digital infrastructure), promoting the use of innovative technologies and the latest teaching aids in the educational process" [20].

The attractiveness of higher education in Ukraine is essential to its concurrency in the international world market. Therefore, another crucial strategic purpose of higher education development is the attractiveness of higher education institutions for study and academic career, which can be realised through an "implementation of … student-centred learning, which is the basis for organising the educational process … using innovative technologies" [20].

Law of Ukraine "On Higher Education" defines four types of higher education institutions for teacher's training and retraining: branch-oriented (pedagogical) university, academy, institute, and college [205]. According to the "Concept of development of pedagogical education", there exists "an imbalance between the public demand for highly qualified teaching staff, the prospects for the development of society, global technological changes and the contemporary system of pedagogical education, as well as the level of readiness/ability of modern teaching staff to perceive and implement educational reforms in Ukraine as one of the important issues" [134], which need to be solved. The Concept emphasises "the mismatch of critical professional competencies of graduates of pedagogical education institutions to the challenges of the digital society" [134, p. 4] and proposes several ways to solve it.

Since Ukraine's policy aims to integrate into the European Union (EU), we should also consider the strategic directions for digitalising higher education in the EU as represented in the Digital Education Action Plan for 2021-2027. It offers a strategy for European education, which includes improved quality and quantity of teaching concerning digital technologies and support for the digitalisation of teaching methods and pedagogies. The Action Plan emphasis to [42]:

- high-quality learning content, user-friendly tools, and secure platforms that respect e-privacy rules and ethical standards;
- good knowledge and understanding of data-intensive technologies like artificial intelligence (AI).

Since 2020 (wide spread of the novel coronavirus), and especially since 2022 (Russia's invasion of Ukraine), the challenges faced by Ukrainian teaching staff in performing and managing emergency distance education have raised many issues.

Information and cognitive technologies, such as AI, human-computer interaction, cognitive computing, information visualisation, and knowledge management, aim to design systems, tools, and interfaces that seamlessly integrate with and complement human cognitive processes. Information and cognitive technologies are increasingly important in education, enabling personalised instruction and improved knowledge acquisition and retention [29, 143, 144].

Information and cognitive technologies in education, like adaptive learning (a prominent application of AI in education, supporting personalised and effective learning experiences [93]), have the potential to revolutionise education by providing more personalised, engaging, and effective learning experiences. By analysing large educational datasets produced by LMSs like Moodle, we can uncover patterns, insights, and trends, enabling data-driven decision-making for educators and administrators.

In the use of information and cognitive technologies in education, we can indicate the following contradictions:

- between the demands on the teaching staff to implement student-centred learning using innovative technologies and the absence of the grounded choice for the appropriate software and methodologies;
- between the variety of Moodle LMS resources and activities to support adaptive learning and the students' outcomes;
- between the existing traditions, biases and regulations on the technology-supported teachers' training in the Kryvyi Rih State Pedagogical University and the real practice of using Moodle LMS to support adaptive learning;
- between the big data produced by Moodle LMS and insufficient use of data-driven

decisions to improve the quality of teachers' training.

Therefore, to resolve the indicated contradictions, we selected the research theme: **"Methodology of using information and cognitive technologies of adaptive learning of pedagogical universities students"**.

Connection of work with scientific programs, plans, topics, grants: Research is related to Grant of Ministry of Education and Science of Ukraine №0121U113711 "Theoretical and methodological principles of designing an immersive cloud-oriented educational environment of the university" which was carried out in Kryvyi Rih State Pedagogical University.

Research object: use the information and cognitive technologies of adaptive learning in higher education.

Research subject: particular elements of the methodology of using information and cognitive technologies of adaptive learning of pedagogical university students.

Research purpose: provide the data-driven evidence-based insights and recommendations on using Moodle tools to implement the adaptive learning of pedagogical university students.

Research questions:

1. What are the key thematic clusters and trends in the literature on adaptive learning in higher education based on keyword analysis, and how do these clusters relate?
2. How interconnected are the different Moodle resources and activities used by teachers of pedagogical universities?
3. How does using the different Moodle tools influence student learning outcomes?
4. Does the use of Moodle tools guarantee the implementation of adaptive learning for students of pedagogical universities?

Research methods:

- bibliometric analysis for the selection of sources from the research problem and the identification of key concepts of adaptive learning in higher education;
- cluster analysis of the bibliometric network to identify problematic areas of adaptive learning;
- cluster-based review to highlight main themes related to adaptive learning in higher education;
- descriptive statistics to summarise and describe data about student assessments and module instances;
- correlational analysis to examine the relationship between assessment and using Moodle tools;
- structural equation modelling to build the conceptual model and to examine the relationships between the model components.

Scientific novelty of the research results lies in the comprehensive examination of adaptive learning in higher education through bibliometric analysis, the development and application of a quantitative model to analyse Moodle tools interconnectedness and their impact on learning outcomes, and the insights into the specific methodology conditions and considerations required for effectively implementing adaptive learning of pedagogical universities students using Moodle tools:

1. A bibliometric analysis identified key thematic clusters and trends in adaptive learning literature, revealing this area's multidimensional and interconnected nature of research.
2. Development and application of a quantitative SEM-PLS model to investigate the relationships between various Moodle LMS resources, activities, and student assessment outcomes, providing insights into the interconnectedness of different Moodle tools used by teachers in pedagogical universities.

3. There is empirical evidence on the influence of different Moodle tools on student learning outcomes, specifically the strong positive relationship between interactive activities and communication/engagement, the moderate positive relationship between resources and learning activities, and the moderate positive relationship between course information and assessment performance.
4. The finding that the mere use of Moodle tools does not guarantee the implementation of adaptive learning for students of pedagogical universities highlights the need for careful instructional design, integration of appropriate pedagogical strategies, and strategic use of Moodle's adaptive capabilities.

Practical significance of the obtained results lies in providing methodology guidance for instructors and course designers to optimise their use of Moodle LMS by emphasising interactive activities, diverse resources, comprehensive course information, and strategic integration of Moodle's adaptive capabilities to enhance student engagement, communication, and learning outcomes in pedagogical universities.

Personal contribuion in the co-authored publications: in [52], the data were collected, digized, and cleaned.

Dissertation approbation. The results of the dissertation were presented at the 18th International Conference on Information and Communication Technologies in Education, Research, and Industrial Applications (ICTERI 2023), 4th International Conference on History, Theory and Methodology of Learning (ICHTML 2023), and VII International Scientific and Practical Conference "Information Technology for Education, Science, and Technics" (ITEST-2024).

Structure and size of the dissertation. The dissertation consists of the abstract, introduction, three chapters, conclusion, bibliography, and two appendices. There are 18 tables, 17 figures, and 155 pages in the dissertation.

CHAPTER 1

Literature review

1.1. Bibliometric review

A bibliometric analysis was conducted using the VOSviewer [21] to systematise available scientific knowledge. To carry out the analysis, a selection of sources from the scientometric database Scopus was made upon request:

TITLE ("adaptive learning") AND (LIMIT-TO (SUBJAREA, "SOCI"))

According to the request, the term "adaptive learning" appeared in the titles of articles, chapters, or books belonging to the subject area "social sciences". As a result, 344 documents were received, and the distribution of works by year is presented in figure 1.1.

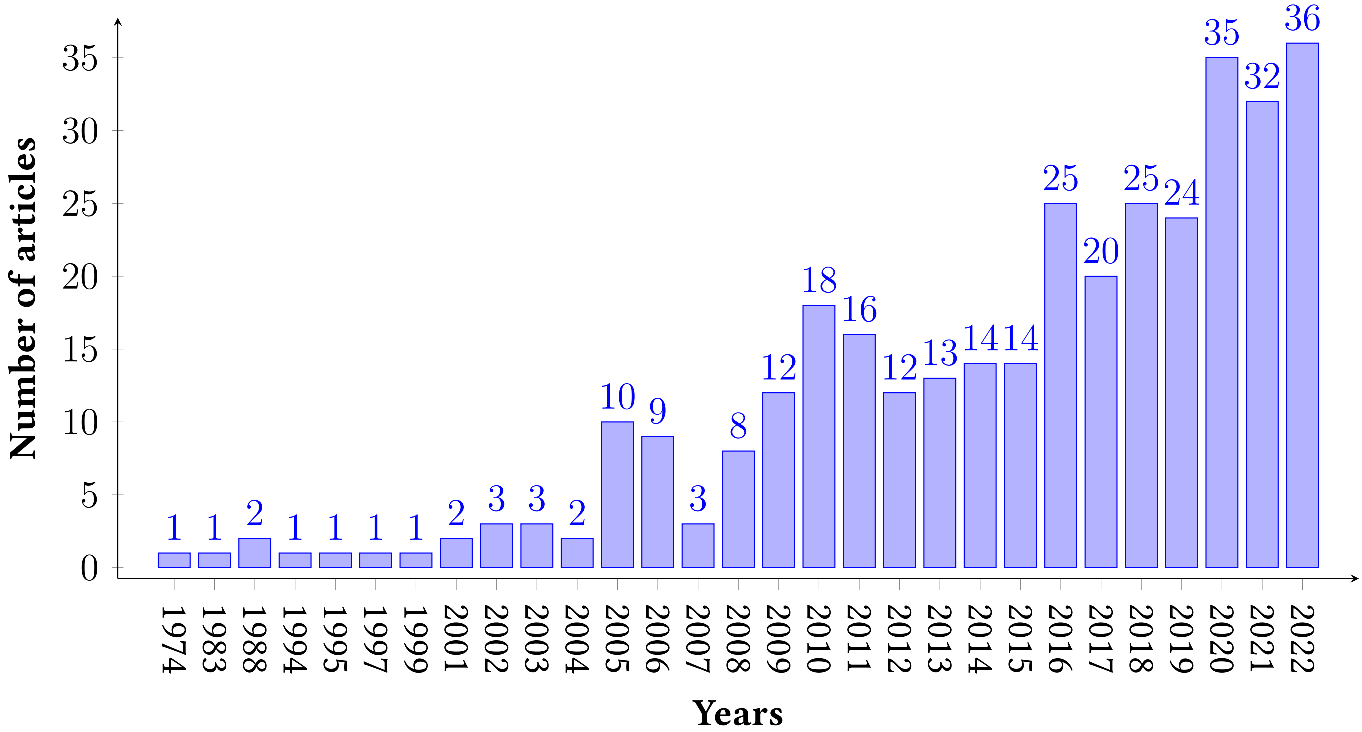


Figure 1.1: Distribution of articles from Scopus database by years.

Cluster analysis by keyword co-occurrence was conducted: from 1836, keywords were selected that appeared at least 10 times (table 1.1).

The results of the cluster analysis are presented in figure 1.2.

Table 1.1: Distribution of keywords by clusters.

Keyword	Cluster	$\text{Weight}_{\text{Links}}$	$\text{Weight}_{\text{Total link strength}}$	$\text{Weight}_{\text{Occurrences}}$	$\text{Score}_{\text{Avg. pub. year}}$	$\text{Score}_{\text{Avg. citations}}$	$\text{Score}_{\text{Avg. norm. citations}}$
adaptive learning	1	29	425	158	2016.0443	10.6076	0.966
learning systems	1	27	445	118	2014.6356	10.6949	0.8159
e-learning	1	27	280	70	2015.4571	6.6857	0.7592
adaptive systems	1	25	126	28	2013.6429	28.3929	1.1589
learning objects	1	22	46	12	2012	24.8333	1.6496
learning style	1	21	72	17	2013.4706	32.4118	1.5342
learning algorithms	1	20	53	13	2015.4615	34	1.6297
learning experiences	1	19	56	11	2015.4545	9.2727	1.1661
artificial intelligence	1	18	41	14	2016.6429	7.8571	0.8118
item response theory	1	18	33	10	2017.3	17.1	1.8503
curricula	1	17	78	21	2014.7143	7.9048	0.8894
personalization	1	14	27	10	2013.9	70.8	3.1478
students	2	26	338	75	2015.68	11.72	1.0332
computer aided instruction	2	25	209	40	2014.975	13.975	1.0588
adaptive learning environment	2	23	82	19	2014.4211	14.5263	1.4182
learning contents	2	20	49	11	2013.6364	11.6364	0.9208
learning performance	2	19	48	11	2014.1818	11.3636	0.8037
intelligent tutoring system	2	17	49	11	2014.5455	22.0909	1.4888
intelligent tutoring systems	2	15	34	12	2017.9167	15.6667	1.9702
adaptive learning systems	3	27	269	66	2015.1667	7.9697	0.8392
education computing	3	25	135	25	2015.96	4	0.5437
engineering education	3	23	121	29	2013.7931	6.8966	0.7189
learning process	3	20	48	12	2016.5833	4	0.5026
adaptive learning system	3	19	58	15	2016.4667	9.8667	0.8269
education	4	25	144	35	2011.8286	11.8286	0.7189
teaching	4	25	133	29	2015.7931	8.1379	0.6896
learning	4	12	38	17	2015.0588	5.9412	0.5421
human	4	5	29	11	2013	12.0909	0.8125
humans	4	5	27	10	2015.5	10.3	0.8126
personalized learning	5	20	79	21	2017.7619	14.5714	1.3967

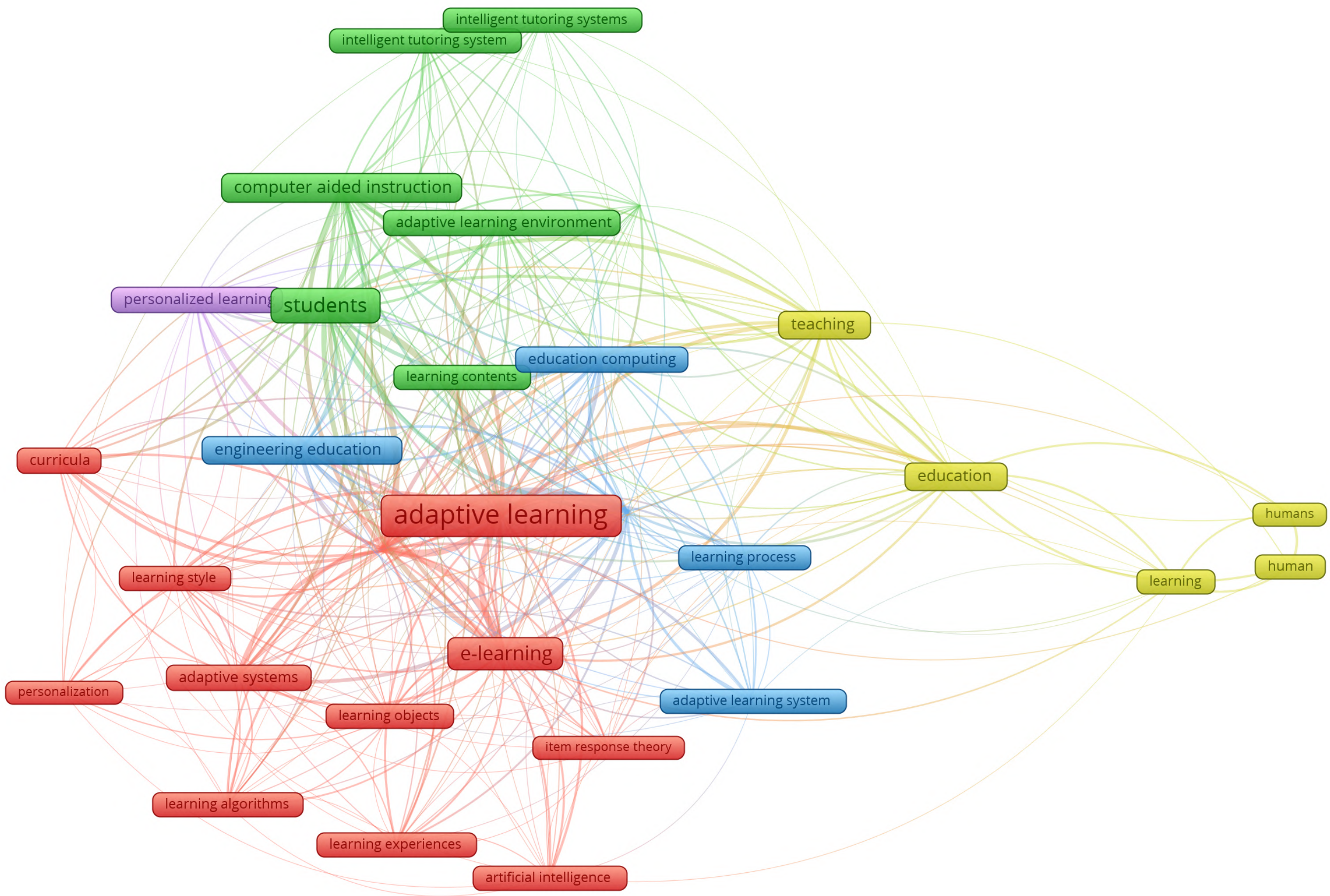


Figure 1.2: Network visualization.

According to table 1.1 and figure 1.2, keywords were divided into five clusters. Let's analyse them in more detail.

The first cluster includes 12 keywords (figure 1.3), 5 of which are primarily related to the theory of adaptive learning: *adaptive learning*, *adaptive systems*, *curricula*, *learning style*, *learning experiences*, *learning algorithms*, *personalisation.* Other concepts are related to adaptive testing (*item response theory*), which is implemented in *e-learning* systems – a type of *learning system* that operate with *learning objects* and can be automated using *artificial intelligence.*

The second cluster contains seven keywords (figure 1.4) related to the practice of *computer aided instruction* of *students* (in particular, assessment of *learning performance*, and evaluation of *learning contents*) at *adaptive learning environment* (in particular, *in-*

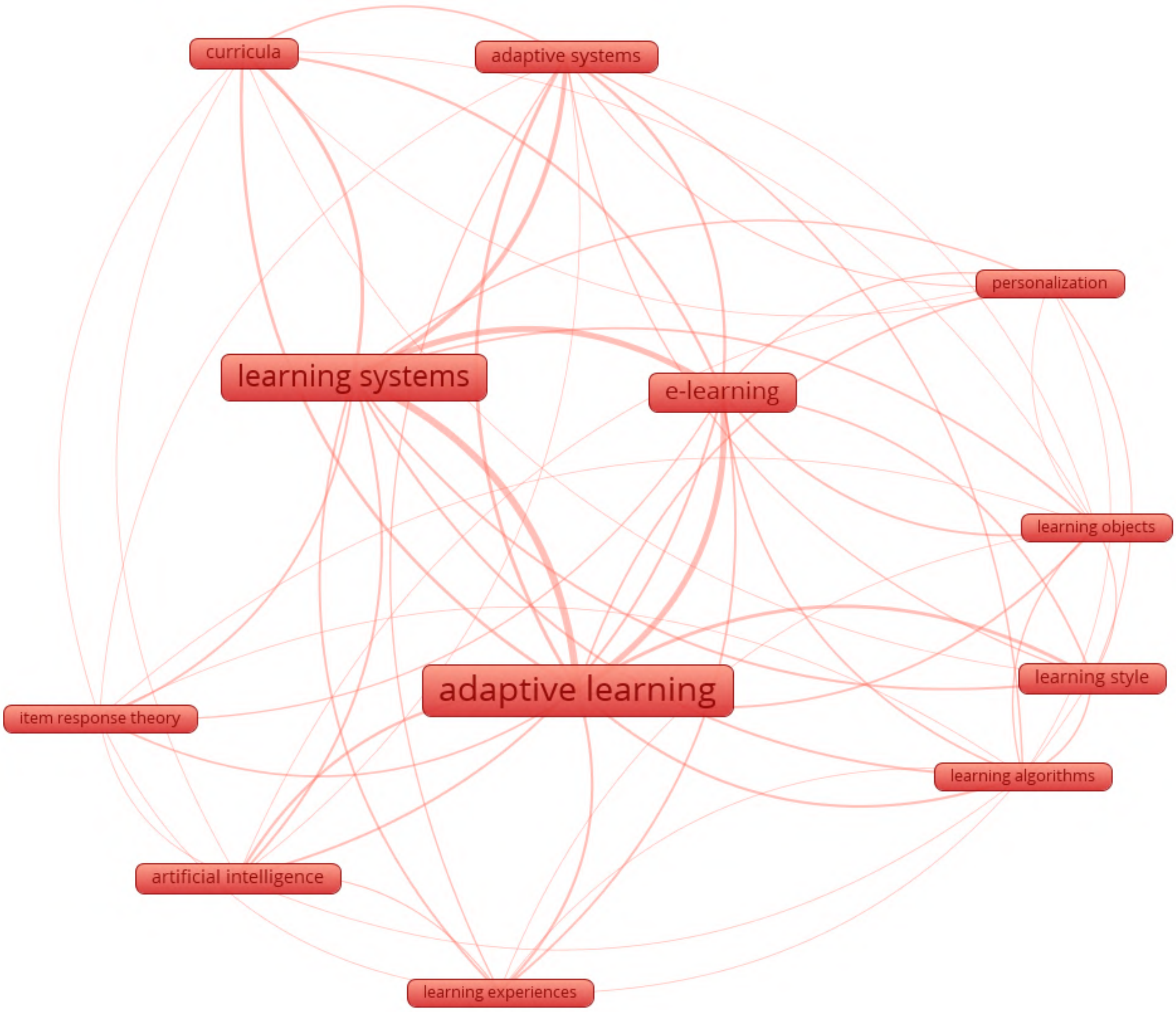


Figure 1.3: A cluster of general adaptive learning concepts in e-learning systems.

telligent tutoring systems).

The third cluster contains 5 keywords (figure 1.5) that describe the implementation of *learning process* within *engineering education* by means of *education computing*, e.g. *adaptive learning systems*.

The fourth cluster also includes 5 keywords (figure 1.6) that describe the didactic fundamentals: *human(s)*, *education*, *teaching*, and *learning*.

The smallest cluster consists of only one keyword (figure 1.5) – *personalised learning*.

Another important criterion for source analysis is density. First was analysing

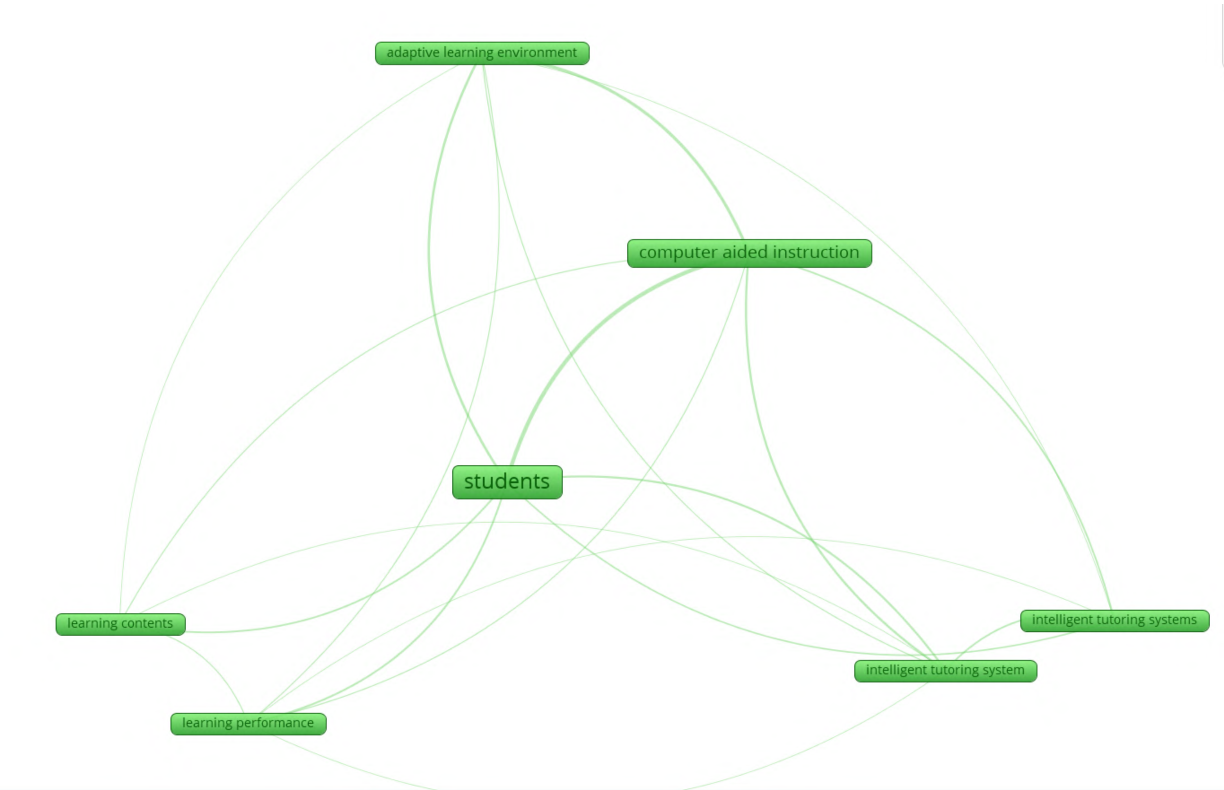


Figure 1.4: A cluster of educational technology.

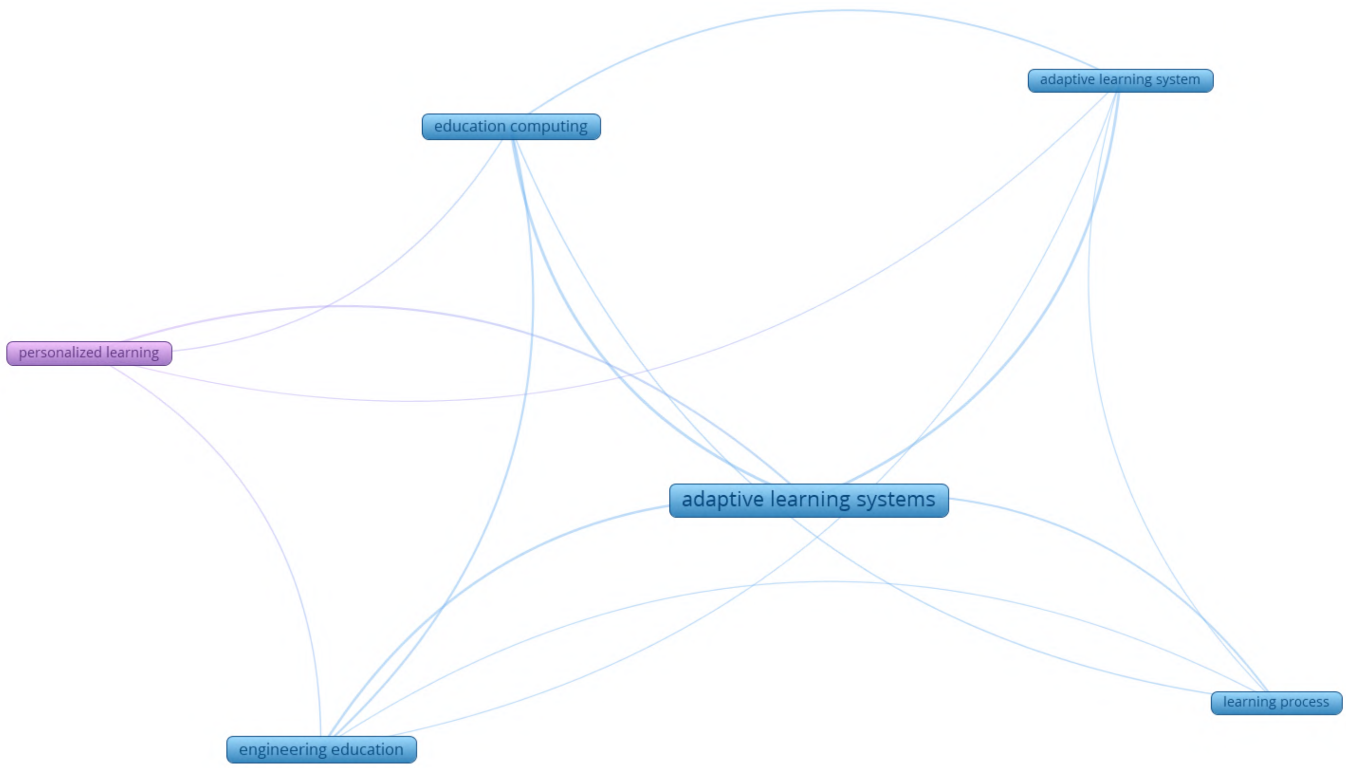


Figure 1.5: A cluster of adaptive learning systems and education computing.

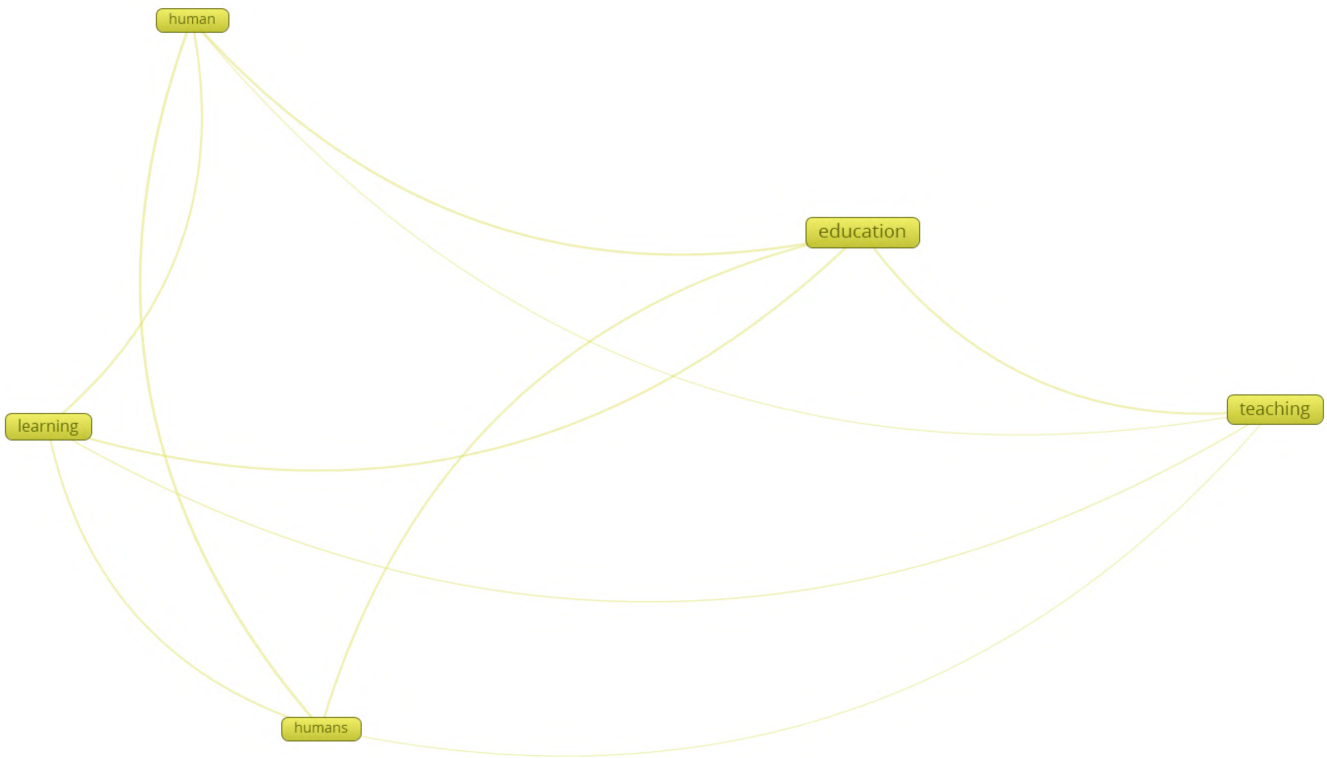


Figure 1.6: A cluster of learning and education research.

the item's density (figure 1.7). From this visualization, the keywords "adaptive learning" ($\text{Weigth}_{\text{Total link strength}} = 425$), "learning system" ($\text{Weigth}_{\text{Total link strength}} = 445$), "students" ($\text{Weigth}_{\text{Total link strength}} = 338$), and "e-learning" ($\text{Weigth}_{\text{Total link strength}} = 280$) have the highest density. These items are the most interconnected (maximum value of total link strength).

To determine primary concepts (earliest keywords by time scale), let's show overlay data visualisation by years. As is shown in figure 1.9, there are no fundamentally new concepts; their emergence and spread have occurred at least since 2020. There are also no concepts that were widespread before 2000. This visualisation gives us grounds for limiting the analysis years.

So, let's analyse these concepts from 2000 to 2020 (figure 1.10). Within these limits, we can see that such concepts as *"human(s)"*, *"education"*, and *"learning objects"* begin to stand out as those that were formed earlier. At the same time, such concepts as *"person-*

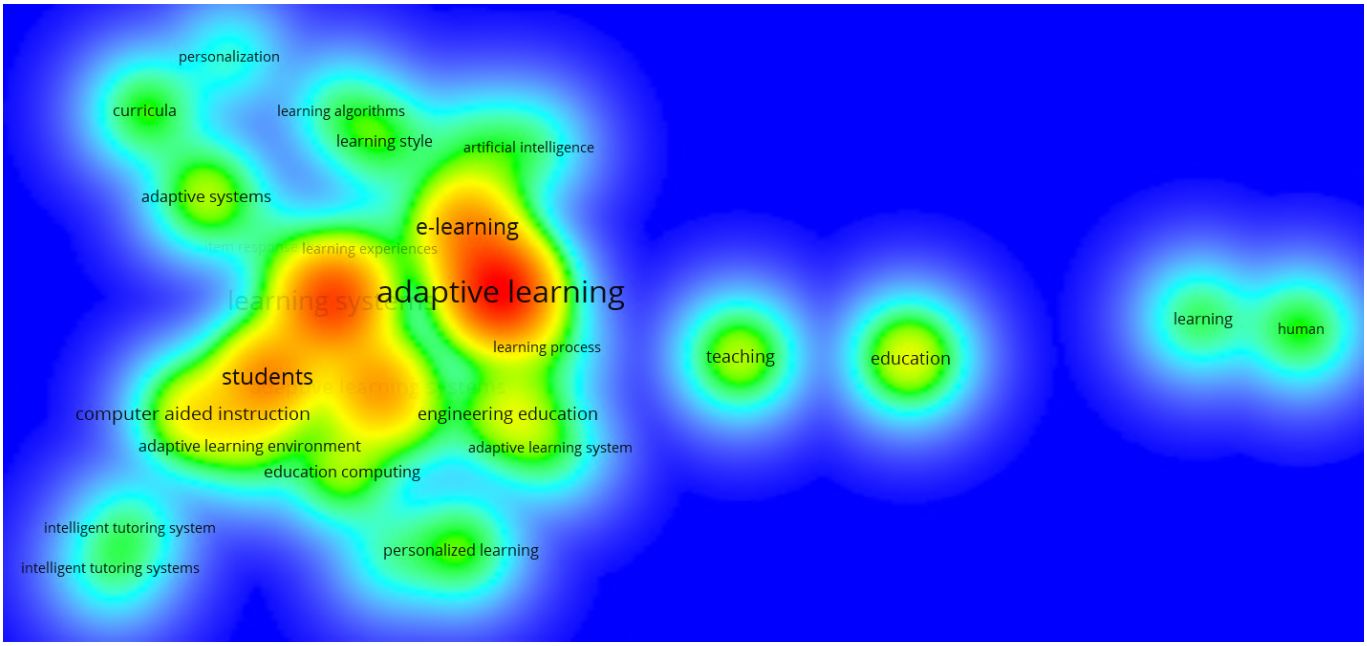


Figure 1.7: Item density visualisation.

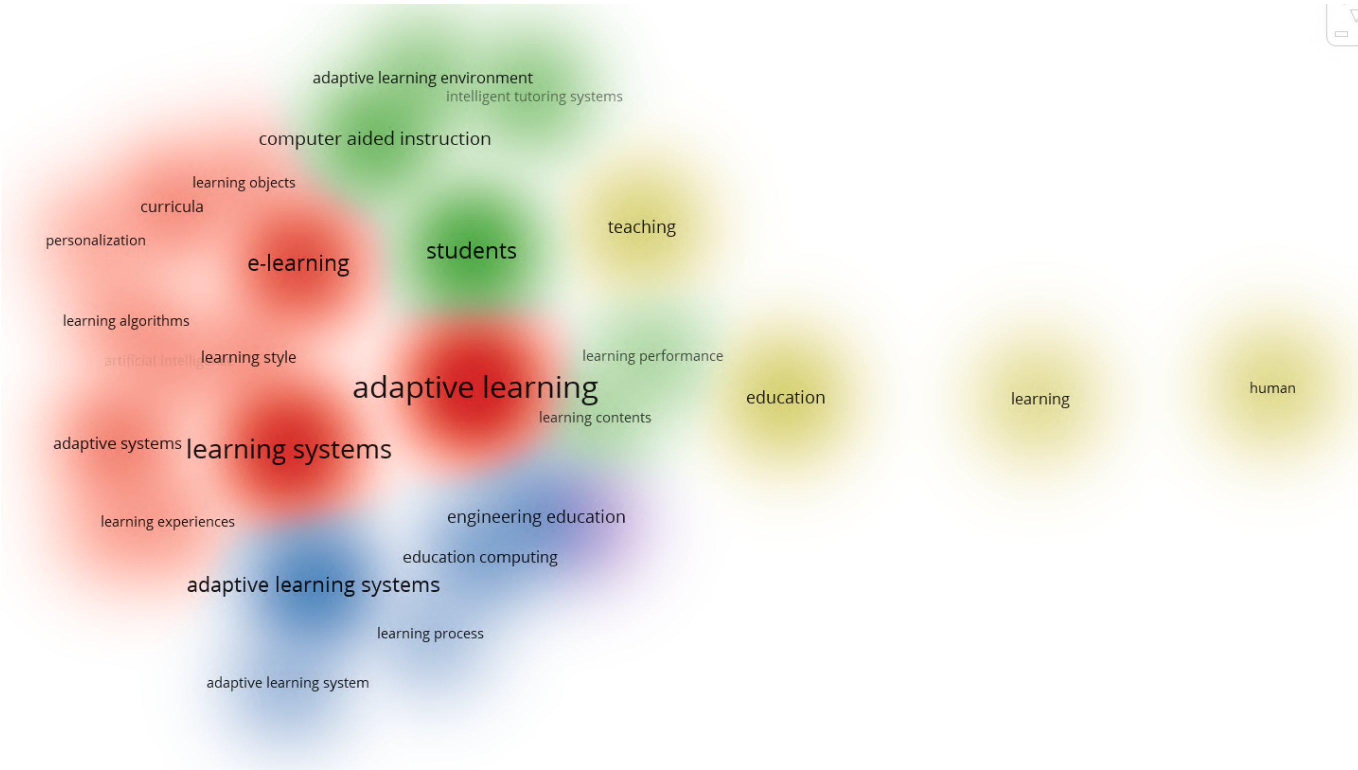


Figure 1.8: Cluster density visualisation.

alised learning" and *"intelligent tutoring systems"* are distinguished as those highlighted later. And since most of the concepts were disseminated after 2000, to see their distribution more accurately, we will raise the lower limit from 2000 to 2010 (figure 1.11).

When comparing figure 1.11 with figure 1.10, we observe that most of the concepts have changed colour, but it is still unclear which concepts were discussed by researchers in the different years.

So, let's try to change both the upper and lower limits for one year, i.e. from 2011 to 2019 (figure 1.12). Now, we can observe a more transparent distribution of concepts by time scale. From this figure, we can see that adaptive learning and artificial intelligence became disseminated later than those related to the use of ICT in education.

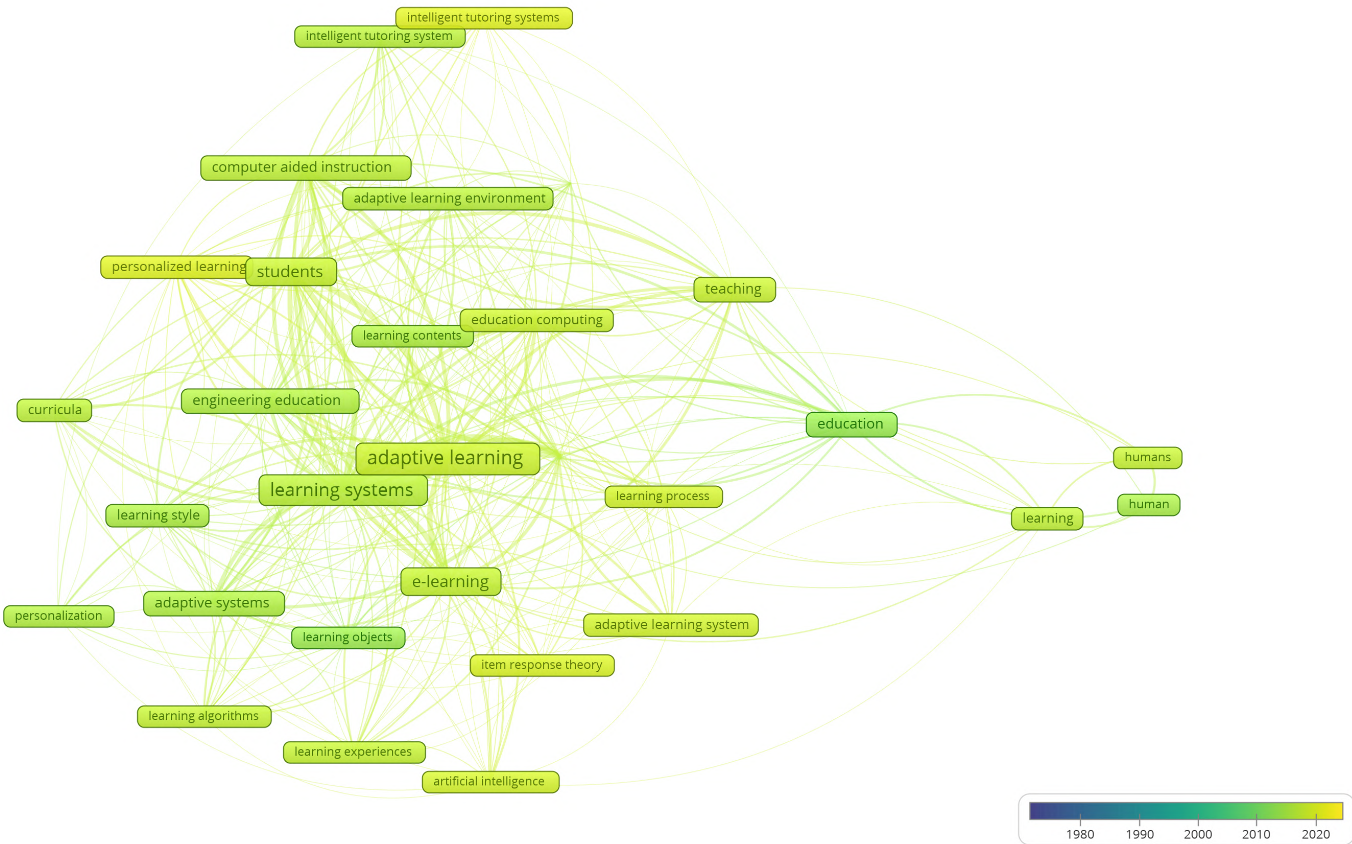


Figure 1.9: Extension of terms from 1974 to 2022.

As a result of the bibliometric review, the following conclusions were obtained:

1. The years of literature analysis from 2011 to 2019 are limited since it is during this period that there is an increasing interest in adaptive learning.
2. With the help of cluster analysis, the problem field of the research was determined.
3. The key concepts are defined: adaptive learning, learning systems, e-learning,

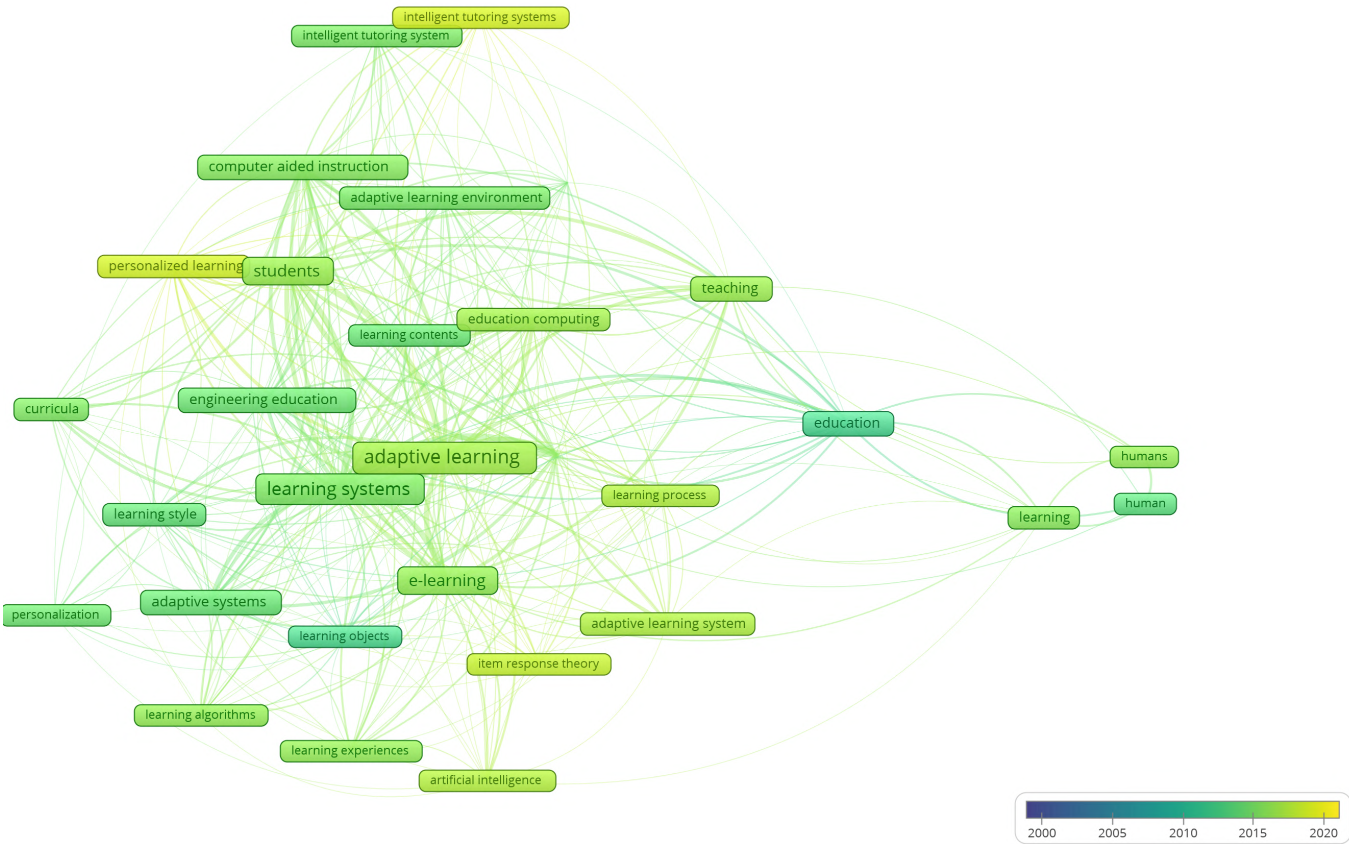


Figure 1.10: Extension of terms from 2000 to 2020.

adaptive systems, learning objects, learning style, learning algorithms, students, computer-aided instruction, adaptive learning environment, learning contents, adaptive learning systems, education computing, engineering education, learning process, education, teaching, personalised learning

4. It was also determined that the COVID-19 epidemic did not affect adaptive learning research.

1.2. A cluster-based review

The analysis allows focus on the detailed study of 163 papers from 2011 to 2019 [2, 4–8, 10, 12–16, 19, 22–28, 30, 32–41, 43–46, 48–50, 59, 61–63, 65–70, 73–86, 89–91, 95–101, 105–119, 121–126, 128, 130–133, 135–137, 139–142, 145–154, 158, 159, 161, 162, 166, 168, 172–174, 176, 177, 180–183, 185, 187–196, 198, 200–204, 208, 212–221, 223–227]. Additionally, 29 PhD theses and technical reports related to adaptive learning systems

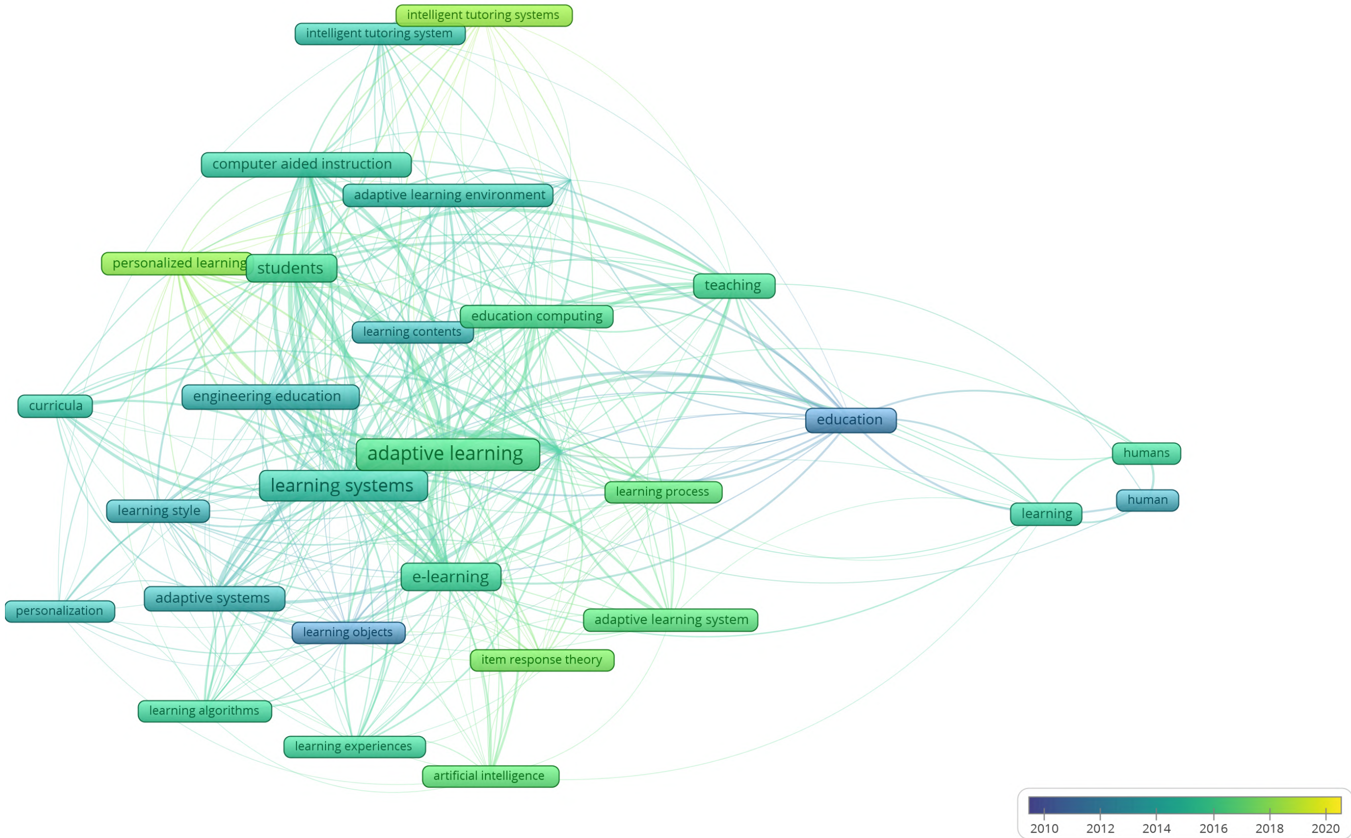


Figure 1.11: Extension of terms from 2010 to 2020.

were reviewed: [3, 9, 11, 17, 18, 47, 57, 58, 60, 64, 88, 103, 104, 120, 127, 129, 156, 157, 160, 165, 167, 175, 179, 184, 186, 199, 209, 210, 222].

1.2.1. A cluster of general concepts of adaptive learning in e-learning systems

A cluster of general concepts of adaptive learning in e-learning systems (in red colour) represented by 67 papers.

Eight papers are related to the *theory of adaptive learning* – a kind of personalised instruction where the learning system dynamically adjusts the learning experience to the individual learner's needs, preferences, and progress. Natriello [141] reviews historical and contemporary work on creating adaptive learning opportunities, identifies active lines of relevant research and development activities, and concludes by identifying issues for further development of adaptive learning applications. Skuballa et al. [187] discusses the advantages of adaptive educational systems and the relevance of eye-

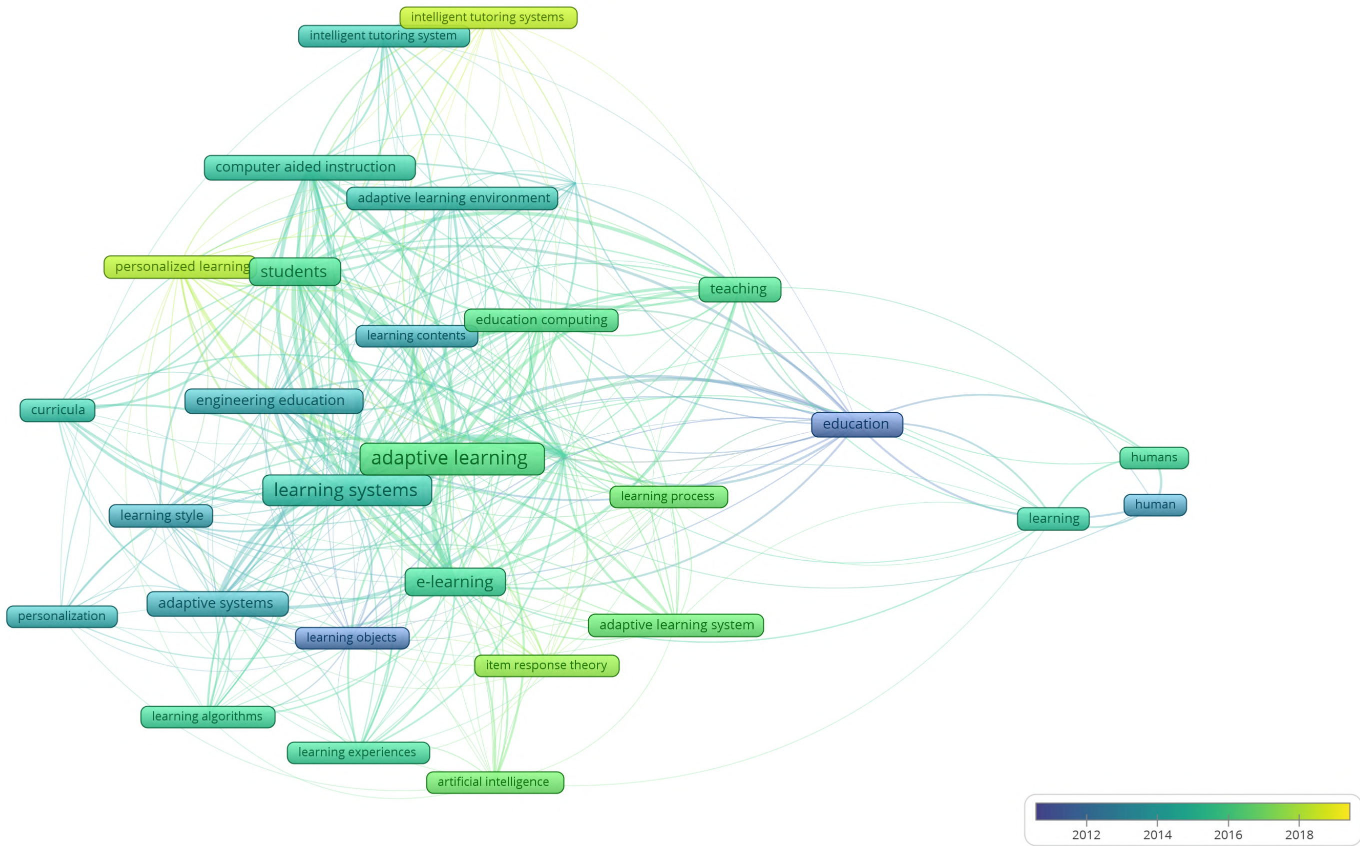


Figure 1.12: Extension of terms from 2011 to 2019.

movement measurements for learning with multiple representations. It also presents initial results on the usefulness of eye-movement assessment in adaptive systems. Aleven et al. [6] discusses the need for adaptive instruction to adapt to learner differences and similarities and suggests using a deep understanding of the demands of a task domain to adapt system design. Chauhan, Taneja and Goel [25] highlighted the need for Massive Open Online Courses (MOOCs) to embrace advanced learning techniques such as Augmented Reality, Adaptive Learning, and Gamification to provide a more engaging experience to learners. Bayounes et al. [15] proposes a faceted framework to understand and classify issues in learning process construction for adaptive learning systems, identifying four different viewpoints and associated facets to capture the diversity of these aspects. Hardy et al. [67] presents an intervention study on an adaptive form of elementary school science education instruction. Lishon-Savarino [116] analyses distance education topics related to the instructional design of developmental mathematics courses at post-secondary institutions that utilise adaptive learning technologies and provides recommendations to improve existing course designs. Hertel, Warwas and Klieme [73] discusses the theoretical definition and empirical investigation of dealing with heterogeneity in educational settings. These papers discuss various aspects of adaptive learning theory, including the history and contemporary work on creating adaptive learning opportunities, the need for adapting to learner differences and similarities, the use of eye-movement measurements in adaptive systems, the construction and classification of issues in the learning process, the effectiveness of adaptive instruction in elementary school science education, and the instructional design of developmental mathematics courses that utilise adaptive learning technologies.

Twelve papers are devoted to personalised course content delivery based on students' learning styles, context awareness, individual characteristics, physiological responses, and other components of the *learner's model*, and provide different approaches and frameworks to improve the quality of learning. Bai et al. [13] establishes an adaptive learning support system for air traffic control, which can determine learning strategies based on learners' styles and significantly improve study efficiency. Ako-Nai et al. [4] presents an adaptive learning content generation platform for mobile learning that is context-sensitive and utilises the 5R adaptation framework to provide the right content to the right learner at the right time and location. Lestari, Nurjanah and Selviandro [107] proposes learning recommendations and adaptive learning based on detecting students' learning styles and working memory capacity to improve the quality of learning itself. Tortorella and Graf [201] proposes a mobile adaptive learning approach for providing personalised course content to students based on their learning style while incorporating adaptive context awareness. An evaluation with 45 students shows that the approach improved comprehension of subject matter by 23% and was popular with students. Pelánek [161] proposed a classification of student performance into several categories based on response times and wrong answers to guide the adaptation of personalised educational systems. Nakic, Granic and Glavinic [139] reviews user individual characteristics as sources of adaptation in recent adaptive learning systems and contributes to the body of knowledge on individual differences in student modelling. Midgley [132] examines the relation between achievement goals, the learning context, and students' and teachers' patterns of cognition, affect, and behaviour, using goal theory as the lens. It provides an overview of the research conducted in this field and suggests future research directions. Hardy et al. [68] investigated the relationship between physiological responses and affective experiences of learners during a programming training session. The study explored skin conductance responses as a physiological measure to design augmented adaptive systems that respond to the learner's cognitive and affective states. Slater et al. [188] surveys math identity measures and correlates them with behaviour and performance in an online math learning system. Shikano and Kittel [185] compares two behavioural models of electoral turnout and presents experimental evidence supporting the model that generates more habitual voting behaviour. Ueno et al. [203] verifies the effectiveness of a model that measures learners' understanding through item response theory in a flipped classroom using an adaptive learning system through case studies in programming and algorithm classes. Ueno et al. [204] proposes a flipped classroom model using an adaptive learning system for C programming classes, which measures the degree of understanding through item response theory. The papers cover topics such as an adaptive learning support system for air traffic control, an adaptive learning content generation platform for mobile learning, learning recommendations based on detecting students' learning style and working memory capacity, mobile adaptive learning approaches, classification of student performance, the use of user individual characteristics as sources of adaptation, the relationship between physiological responses and affective experiences of learners, surveys of math identity measures, and comparisons of behavioural models of electoral turnout.

Seven papers and 1 PhD thesis are devoted to the *development of the adaptive e-learning system.* Kaw et al. [99] describes developing and implementing an adaptive learning platform for a Numerical Methods course, including analytic data and student focus group feedback. Panicker et al. [159] discusses developing and testing an adaptive learning system using rule-based logic for undergraduate courses, with analytics serving as instructor feedback. Werlen and Bergamin [217] conducted a preliminary study on self-evaluation as a source of learning data for sensors of an intended adaptive learning system, which showed moderate correlation with external evaluation and provided insights into designing corresponding sensors. Heiyanthuduwage, Schwitter and Orgun [70] introduced an adaptive learning system that relies on a domain-specific ontology to overcome terminological and structural differences among educational institutions. The system's plug-and-play architecture and reasoning services were demonstrated in the study. Matthews et al. [123] discusses developing and implementing an adaptive learning and grading system to improve feedback quality for computer skills. Matar [122] proposes a structure for an Adaptive Learning Object Repository to provide adaptability in unified e-learning environments. Oliveira et al. [154] suggests a conceptual framework for integrating adaptive hypermedia into learning management systems from a cognitive-semantic perspective. Vu Minh [209] proposes a set of criteria for certain aspects of constructivism and uses both as guidelines for designing learning systems and evaluating the conformity of learning systems with constructivist principles. Based on the criteria for cognitive flexibility, the author proposes an operational instructional design process and introduces an adaptive e-learning platform that may be used for designing adaptive learning systems supporting cognitive flexibility in various domains.

Ten papers primarily focus on the *use of AI in developing and improving adaptive learning systems*. Su [192] proposes an adaptive learning path recommendation system for e-learning that outperforms other approaches, using a novel hybrid approach based on the fuzzy Delphi method, fuzzy ISM, and Kelly Repertory Grid Technology. Zhou et al. [225] provides a new insight into the non-convergence issue of Adam, an adaptive learning rate method, proposing a novel technique called AdaShift that decorrelates gradient and second-moment terms to address the non-convergence problem while maintaining competitive performance. Huang, Yang and Lawrence [79] proposes a classification-based approach to improve the accuracy and reduce the computational complexity of data mining-based concept map generation in adaptive learning systems. Hämäläinen, Kumpulainen and Mozgovoy [82] discusses the clustering of student data, which is a central task in educational data mining and the design of intelligent learning tools. The authors evaluate the main clustering methods and suggest the most promising strategies for different situations. Kardan, Imani and Ebrahim [98] proposed a novel two-stage adaptive learning path algorithm, called ACO-Map, that discovers groups of learners based on their knowledge patterns and applies ant colony optimisation to find a learning path based on Ausubel Meaningful Learning Theory. Schaul and LeCun [177] proposes an algorithm for stochastic gradient descent that automatically adjusts learning rates without manual tuning, addressing issues of minibatch parallelisation, sparse or orthogonal gradients, and non-smooth loss functions. Nguyen [146] proposes a new approach to manage learner modelling in an adaptive learning system using a Bayesian network and overlay model. Nurjanah [149] discussed the design of a learner model ontology for lifelong learning to support adaptive learning systems, which classified learners' attributes into static and dynamic attributes. Oke et al. [153] discusses how machine learning, adaptive learning, and data analysis can cater to each student's individual needs based on their psychological concepts like brain dominance and multiple intelligences. Cho, Raiko and Ilin [26] presents an enhanced gradient and a way to automatically adjust the learning rate to improve the training of restricted Boltzmann machines. The listed works discuss various approaches and algorithms, such as fuzzy Delphi method, AdaShift, classification-based approach, clustering methods, ant colony optimisation, stochastic gradient descent, Bayesian network and overlay model, learner model ontology, machine learning, and data analysis, to improve the performance, accuracy, and complexity of adaptive learning systems, addressing issues such as non-convergence, sparsity, non-smooth loss functions, and learner modelling, while catering to individual student needs based on their psychological concepts like brain dominance and multiple intelligences.

Ten papers and 3 PhD theses describe *algorithms and approaches in adaptive learning systems*, including an improved ant colony algorithm for online learning, a bio-inspired system for reduced energy consumption, a technique for recommending learning materials, and a negotiation-based approach for combining adaptivity and adaptability. Li [110] proposes an adaptive online learning system that uses an improved ant colony algorithm to cater to learners' preferences, tastes, and knowledge levels. Martinez et al. [119] focused on designing and implementing a bio-inspired adaptive learning system using cerebellar model articulation controller principles, which showed reduced energy consumption with improved throughput and convergence. Vo and Dutkiewicz [208] presents an algorithm for data segmentation in arrhythmia detection, utilising an adaptive learning scheme to improve classification performance. Nurjanah [148] proposed a new technique for recommending learning materials in adaptive learning systems that combines content-based filtering and collaborative filtering based on the similarity between learners' and learners' competence. Rimbaud et al. [172] investigates the use of the Content and Language Integrated Learning approach and mixed methods to develop algorithms for adaptive learning to meet the needs of learners in an additional language. Anderman and Midgley [10] provides an overview of the methods used in a large-scale longitudinal study examining young adolescents' emotional, social, and academic well-being using goal orientation theory. Chaoui and Laskri [23] proposed the "Fusion of Web Resources" approach to creating an adaptive learning domain in an e-learning platform. The approach enables the extraction of relevant educational web resources, filtering and structuring them into courses, and adapting the courses to learners' profiles. Lai, Chou and Lan [105] proposes a negotiation-based approach to combine adaptivity and adaptability in adaptive learning systems, where the system suggests adaptations and the student negotiates if their preference differs. Miyagi [137] proposes an algorithm based on smooth fictitious play and regret matching models to establish behavioural rules of route choice under incomplete information in traffic environments. Wang and Liao [215] proposes a five-step algorithm based on four learner characteristics to develop an adaptive learning sequence system for English as a Second Language instruction. Borsuk [18] proposes the structure of a functional simulator with adaptive algorithms as a software tool for the organisation of training and knowledge control of the aviation specialist industry. The author has developed adaptive algorithms for each of the subsystems of the simulator, which allow for the influence of such parameters of the training process as the proportion of time intended for work in different systems of the simulator. Pogrebniuk [167] presents the model of adaptive learning scenario development for distance learning with the use of Petri nets, depending on specific characteristics of the student's model (academic background, test results, maps of the gaps in knowledge, curve of forgetting). The IRT-based model for developing adaptive testing scenarios offered by the author reduces the test length and testing time. Fasihuddin [57] proposes using knowledge maps and adaptivity to individual learning styles using adaptive navigational support technology for enhancing open learning environments.

Six papers on the *implementation and effectiveness of adaptive learning systems in education*. Mirata and Bergamin [136] discusses the challenges preventing higher education institutions from adopting adaptive learning technologies and proposes an implementation framework based on empirical data from two universities. Lin and Wu [113] explored the effectiveness of an adaptive learning platform with flipped classroom instruction on elementary school students' learning performance and self-learning approach. Rosen et al. [174] reports on an experimental implementation of adaptive learning in a self-paced Microsoft MOOC on edX, which showed that adaptivity in assessment, with emphasis on remediation, led to a substantial increase in learning gains. Basitere and Ivala [14] evaluates the effectiveness of an adaptive learning platform in improving learners' performance in a first-year introductory engineering physics course. Results show a positive relationship between proficiency scores and enhanced performance in the paper-based midterm test. Dziuban et al. [46] presents the results of a pilot study on using an adaptive learning platform for an online General Psychology course, indicating students found it easy to use and successful, but an early prediction of at-risk students is possible using learning outcome metrics. Jonsdottir, Jakobsdottir and Stefansson [91] describes a system for computer-assisted education that offers interactive drills to increase learning and investigates what affects students' decision to stop working. These studies provide insights into the challenges of adopting adaptive learning technologies in higher education institutions, the effectiveness of such systems in improving students' learning performance in different subject areas and grade levels, and the ease of use of adaptive learning platforms. Additionally, the studies highlight the potential for early predicting at-risk students using learning outcome metrics. These findings provide valuable information for educators and administrators interested in implementing adaptive learning systems to improve student learning outcomes.

3 papers on the *evaluation of adaptive learning systems in education. Evaluating adaptive learning model* [49] describes adaptive learning as a trend in modern education and discusses user modelling as the heart of adaptive learning systems. The paper proposes evaluation criteria for adaptive learning systems and gives an evaluation scenario as an example. Nussbaumer et al. [150] presents an evaluation service that supports the evaluation of adaptive learning systems, using a layered evaluation approach to define qualities that are evaluated individually. The evaluation service supports the whole evaluation process, including modelling, data collection, and automatic reports based on data analysis. Albert and Steiner [5] aims to advance the maturity of evaluation approaches for adaptive learning technologies by stimulating discussion and dialogue on future research directions.

Eleven papers and 1 PhD thesis provide examples of various *adaptive learning platforms* that have shown their effectiveness in improving student performance and providing positive learning experiences, ranging from platforms that use crowdsourcing to improve learning outcomes to systems that manipulate student characteristics to offer personalised learning, to serious game adaptive learning systems. Grother [66] highlights the benefits of crowdsourcing questions for revision and consolidation of knowledge, specifically through the free platform PeerWise, which has been shown to improve performance in summative assessments. Sfenrianto et al. [181] proposed an adaptive learning system-knowledge level to personalise materials according to the proficiency level of English language learners, which improved learners' proficiency and reduced the number of learners with elementary level. Li et al. [109] presents the YiXue adaptive learning platform, which was more efficient than two comparison platforms in an after-school English language arts course in China. Linden et al. [115] presents an adaptive online neurophysiology lesson using the Smart Sparrow platform that shows significant promise in enhancing student learning in a problematic first-year subject. Lin, Wu and Cheng [114] reports on the Adaptive E-learning for Science Project in Taiwan. It aims to develop an adaptive science learning system for primary science teachers and examines its effectiveness using adaptive dynamic assessment in adaptive learning. Allison and Extavour [8] evaluates the experiences of first-year pharmacy students in Trinidad and Tobago using adaptive learning technology in the form of a SmartBook for an Anatomy and Physiology course. The study finds that the SmartBook supported learning and provided positive learning experiences. De Santana et al. [39] examined the "Mars and Venus Effect" by investigating the use of an adaptive learning technology called Meu-Tutor on 191 students from public schools in Brazil. Results showed that the technology improved male and female students' performance in Mathematics and Portuguese, with male students showing more significant improvement in Mathematics. Heffernan et al. [69] explored the potential of crowdsourcing contributions from teachers and students to perpetually improve adaptive learning technologies, using online platform ASSISTments as an example. Nguyen [145] proposes a novel user modelling system named Zebra, which manipulates students' characteristics effectively to provide personalised learning. Zebra has a powerful inference mechanism for explaining new information about students to support adaptive learning. Obikwelu and Read [152] reviewed the literature on the different adaptation logics embodied in existing serious game Adaptive Learning Systems. The study investigated various ALS, including NUCLEO, S.M.I.L.E, Framework for Adaptive Game Presenters with Emotions and Social Comments, Fine-Tuning System, and ALIGN. De-La-Fuente-Valentín, Pardo and Kloos [37] proposes an extension to the IMS Learning Design specification to allow bidirectional communication between the course engine and third-party tools, enabling the customisation of learning experiences. Aguar [3] develops an adaptive learning framework for STEM education. This research takes an approach by adapting content and practice problems based on a student's interests. This work presents the design and pilot of the system for adaptive interest-based learning, which is designed to help alleviate many of the concerns in STEM education by providing a competent and compelling curriculum delivering individualised instruction to help increase motivation and performance and fill the gaps in STEM education.

1.2.2. A cluster of educational technology

A cluster of educational technology (in green colour) represented by 50 papers.

Nine papers are focused on the *use of AI-related technologies and methods in the development of adaptive learning systems*. Palomino, Silveira and Nakayama [158] describes an intelligent or adaptive learning management system based on multiagent systems that use software agents to personalise and adapt the learning experience according to each user's way of learning. Chaplot, Rhim and Kim [24] proposes a new adaptive learning system architecture that uses Artificial Neural Networks to construct the Learner Model and select items of optimal difficulty personalised to the student's skill level and learning rate. Zhang [223] proposes a multiagent system for adaptive learning environments that offers flexibility in the presentation of material and a greater ability to respond to distinctive student needs. Mavroudi, Giannakos and Krogstie [125] conducted a systematic review of twenty-one peer-reviewed studies and identified the interplay between learning analytics and adaptive learning and the need for further research on the topic. Afini Normadhi et al. [2] conducted a systematic literature review to identify the most commonly used personal traits in modelling the learner and the existing techniques for identifying personal characteristics in an adaptive learning environment. Most previous works used a learning style from the cognition learning domain category to model individual personal traits. At the same time, the computer-based detection technique was commonly applied to identify a learner's traits. Wang et al. [214] used K-means clustering to identify three clusters of middle school students based on prior achievement and found that the Yixue intelligent learning system was able to help students from different achievement levels learn equally well in mathematics. How and Hung [75] proposes an approach for educational stakeholders to employ Bayesian networks to simulate predictive hypothetical scenarios with controllable parameters to evaluate an AI-ALS for its suitability in enhancing students' problem-solving abilities. Sosnovsky and Chacon [190] proposes a mechanism for detecting metadata gaps in collections of learning content by converting learning objects metadata into an OWL2 ontology, detecting logical conflicts, and generating human-readable explanations. Tsai and Huang [202] investigated the factors impacting high school students' adaptive learning using machine learning approaches such as neural networks and decision tree analysis. The authors found that the school teaching environment was the main factor impacting students' adaptive learning. These studies describe different aspects and approaches to adaptive learning design, including multiagent systems, artificial neural networks, machine learning algorithms, and ontology-based mechanisms. They discuss various factors impacting adaptive learning, such as individual personality traits, prior achievement levels, and the school teaching environment. Overall, the studies highlight the growing interest in developing adaptive learning systems that can personalise the learning experience and enhance students' problem-solving abilities, an essential goal of AI in education.

Two papers are related to *the use of IRT to adapt learning*. Huang and Shiu [78] discusses the challenges of finding suitable learning paths and content on e-learning

2.0 platforms and proposes a user-centric adaptive learning system that uses sequential pattern mining and Item Response Theory (IRT) to construct adaptive learning paths and estimate learners' abilities for recommending adaptive materials. The experimental results show that the effectiveness of UALS is comparable to expert-designed learning, and guidelines for designing e-learning 2.0 platforms are proposed. Pliakos et al. [166] propose a system that combines item response theory (IRT) with machine learning to predict the proficiency of new learners entering an adaptive learning environment, addressing the cold-start problem. The hybrid model combining IRT with Random Forests provided the best results.

Nine papers provide a broad overview of the current research and developments in the field of *adaptive learning environments*. Gasparinatou and Grigoriadou [62] describes the development of an adaptive learning environment for computer science students called ALMA, which uses Kintsch's Construction-Integration model for text comprehension and various activities to assess and support learner comprehension. De Marsico, Sterbini and Temperini [38] proposes integrating two web-based e-learning systems, LECOMPS and SOCIALX, to provide personalised and collaborative learning in line with Vygotsky's social-cultural theory. Graf et al. [65] provides an overview of adaptive and intelligent learning systems and how they can be integrated into various learning environments to improve the learning experience for learners and teachers. Massey et al. [121] introduced perceptual learning modules in middle and high school mathematics, showing that appropriately designed PL technology can produce rapid and enduring advances in learning. Daniello et al. [35] proposes a flexible, seamless learning environment that identifies a learner's context and applies adaptation by respecting their learning goals using situation awareness, adaptive learning, and semantic technologies. Mavroudi et al. [126] presents a participatory design process for an adaptive learning environment and suggests a methodology of framing key requirements into a set of critical success factors for meeting the end-users expectations. Isaksson, Naeve and Lefrère [86] explores the reconceptualisation of learning environments as performance augmentation through ubiquitous and adaptive learning and work environments. Yuan et al. [221] investigates the utility of gesture-based interaction in adaptive learning environments based on theories of embodied cognition. It applies gesture-based technologies within an adaptive learning system and found that the learners in the gesture-based group significantly outperformed the learners in the mouse-based group. Szijarto and Cousins [195] studied developmental evaluation and how mediators influence the relationships between components of a social learning system in adaptive learning. They found that evaluators making space for interrogating ideas and choices employed strategies such as turning down the heat, seeking balance, normalising evaluation practice, and legitimising DE. The study has implications for evaluation capacity building in adaptive learning contexts.

Thirteen studies and one technical report are related to *adaptive learning systems design and development*. Rodrigues Pereira et al. [173] discusses the development of the OAEditor framework, which allows teachers to create educational hyper documents that adapt to students' performance and include self-evaluative questionnaires for monitoring progress. Fidalgo-Blanco et al. [59] suggests breaking the organisational structure of learning content management systems to manage the learning process individually and adapt resources to the profile and needs of each student. The system presents an emergent window to the student with the most valuable resources available. Clougherty and Popova [30] argues that adaptive learning design should be developed before tool implementation and is not limited to course-based adaptation. The Seven Model Approach illustrates the range and degree of adaptivity that can be modified based on the granularity of the learning elements. Essa [48] discusses the possible future of designing next-generation adaptive learning systems based on new developments in learning science and data science. Minkovska, Ivanova and Yordanova [135] discusses the design principles of interactive eLearning and presents a prototype of an adaptive eLearning system that improves students' understanding and assists educators in teaching and assessment. Chou et al. [28] presents a negotiation-based adaptive learning system that regulates students' help-seeking behaviour. Gavrilović et al. [63] presents an algorithm for creating an adaptive learning process to improve learners' knowledge and skills in Java programming language. Sun, Norman and Abdourazakou [193] examines the perceived value of LearnSmart, an interactive digital textbook, and its implications on adaptive learning and student learning effectiveness. LearnSmart was found to improve students' perceived competency and satisfaction, thus increasing their perceived value of using it, with varying perceived value across different course delivery formats and devices. Shelle et al. [183] discusses the use of adaptive learning tools in Extension programming and found that it aided learners in mastering content. Nye et al. [151] investigated the learning outcomes and user perceptions of a hybrid intelligent tutoring system created by combining the AutoTutor conversational tutoring system with the ALEKS adaptive learning system for mathematics. Qu, Cai and Haj-Hussein [168] describes a project that integrated adaptive learning software, Amazon Web Services, and discussion board assignments to create an Online Learning Environment suited to Bachelor of Science of Computer Science and Information Technology degree programs. Surahman et al. [194] aimed to develop online learning services that can adapt to learners' characteristics and learning styles, resulting in effective learning outcomes that exceeded targets. Chou et al. [27] proposes a negotiation-based approach for combining system-controlled and user-controlled adaptation in adaptive learning systems. The system suggests adaptations, but the student also submits their adaptation preference, and if they disagree with the system, they negotiate an agreement. This approach improves metacognition and performance in students. Shyshkina [186] developed methods of using the adaptive cloud-based system of training and professional development of teachers of general secondary education institutions.

These studies explore approaches, frameworks, algorithms, and prototypes used in adaptive learning systems. These include negotiation-based approaches, interactive eLearning, hybrid intelligent tutoring systems, and online learning services that adapt to learners' characteristics and learning styles. They also highlight the importance of developing an adaptive learning design before tool implementation and breaking the organisational structure of learning content management systems to manage the learning process individually and adapt resources to the profile and needs of each student.

Six papers are related to the *personalisation of education with adaptive learning systems*. In Yang, Hwang and Yang [218], an adaptive learning system was developed based on personalised presentation modules for computer science students, resulting in significantly better learning achievements than the control group. Walkington [213] showed that an interest-based personalisation intervention within an intelligent tutoring system for secondary mathematics improved learning outcomes for struggling students. Indrayadi and Nurjanah [85] discusses approaches to improving adaptation and personalisation in adaptive educational hypermedia. It presents a knowledge map that combines individual learner progress and preference with peer experiences to strengthen adaptation and implements an open learner model to nurture self-progress awareness. Natriello and Chae [142] discusses the growth of adaptive learning technologies that claim to support personalised learning experiences. Miller, Asarta and Schmidt [133] examines the effects of different deadline strategies on student participation and performance in adaptive learning assignments in a face-to-face macroeconomics course. The study found that rigid deadlines negatively impacted participation, but the assignments still positively contributed to exam and homework performance. Extavour, Ocho and Allison [50] evaluated students' perceptions and attitudes towards an adaptive learning technology used in a nursing pharmacology course and found that the technology was positively received by students and resulted in higher course marks than the traditional class. These papers discuss the development and evaluation of personalised presentation modules, interest-based personalisation interventions, approaches to improving adaptation and personalisation, and the effects of different strategies on student participation and performance.

Three papers and 1 PhD thesis are related to *adaptive learning gamification*: Durieu, Solal and Tercieux [44] discusses a study on perturbed joint and independent fictitious play processes in n-person games and how they relate to the selection of strategies in the long run, Del Blanco et al. [40] discussed the integration of digital games in virtual learning environments, using a middleware architecture to integrate video games in VLEs, and Johnson and Zaiane [89] proposes an online Intelligent Tutoring System gamified to teach medical imaging. Ghaban [64] proposes a model of adapting the gamification elements that can predict the best combination of gamification elements for a learner's personality profile.

Four papers primarily focus on *teaching methodology and the use of adaptive learning systems to enhance learning outcomes.* Yang et al. [219] investigates the effectiveness of critical thinking-infused adaptive English literacy instruction using a Moodle system. Results demonstrate that CT-enhanced adaptive English literacy instruction simultaneously improves students' CTS and English literacy, and students' online discussions develop towards higher levels of interaction. The study illustrates an effective blended learning model for adaptive instruction and recommends designing CT-infused language learning activities. Kakosimos [97] presents a teaching methodology for providing students with feedback before lectures and adapting course content accordingly. This methodology was tested and demonstrated in a Chemical Engineering Fluid Operations course, and improvements were made in students' engagement and motivation. Kerr [101] is part of a series that aims to discuss and demystify technology-related themes and topics for English language teachers. Johnson [90] highlights the challenge for educators to prepare teachers for the increasingly diverse and complex learning contexts shaped by globalisation, technology, and other factors.

Four papers explore the effectiveness of adaptive learning systems in improving learning outcomes, the *role of learning styles* and other factors in their design and implementation. Hwang et al. [81] investigated whether students could choose the best-fit e-learning systems for themselves, concluding that developing adaptive learning systems based on learning styles is essential. Chang et al. [22] describes developing an adaptive learning management system that assesses students' learning styles and uses Mashup technology to provide supplementary learning materials. An experiment showed that the system improved learning outcomes and was well-received by participants. Dziuban et al. [45] examines an adaptive learning partnership between universities and Realizeit, finding that the adaptive modality stabilises learning organisation in multiple disciplines. Serrao-Neumann, Cox and Low Choy [180] proposed a conceptual model to identify components of adaptive learning for natural resource management and validated it through on-ground experience, offering insights to enable bridging between adaptive learning and NRM outcomes.

1.2.3. A cluster of adaptive learning systems and education computing

A cluster of adaptive learning systems and education computing (in blue colour) represented by 18 papers.

Five papers relate to integrating learning styles, developing computer-based science learning media, proposing adaptive learning frameworks, exploring adult constructive-developmental theory, and recommending learning paths based on learners' knowledge and course topics. Aljojo et al. [7] presents an approach to integrating learning styles into an adaptive e-learning hypermedia system and evaluates the impact of such a system on students' learning. Zulfiani, Suwarna and Miranto [227] developed a computer-based science learning media that accommodated students' learning styles, producing a system declared valid and effective for different types of learners. Ibrahim and Hamada [83] proposes an adaptive learning framework that classifies learners based on individual preferences regarding understanding and processing information, generating a learning style and suggesting learning content accordingly. Stewart and Wolodko [191] explores Robert Kegan's adult constructive-developmental theory and proposes that university teaching practitioners at different meaning-making levels may benefit from adaptive approaches to the application of interactive pedagogies and digital technologies. Fiqri and Nurjanah [61] discusses a modified Dijkstra algorithm that recommends learning paths based on learners' knowledge, the weight of topics in a course, and the influence scores of each topic, considering the possibility of success in learning a topic.

Six papers and 2 PhD theses relate to intelligent tutoring systems and adaptive learning approaches (primarily in mathematics education), discussing their effectiveness, benefits, and the design of personalised learning experiences using different methods. Walkington and Sherman [212] investigates the effectiveness of context personalisation within an intelligent tutoring system for Algebra I students and how it facilitates algebraic symbolisation. Li et al. [112] discusses the advantages of adaptive learning, which can provide personalised learning experiences for students. It describes a model that simplifies the concept map and presents the learner's cognition abilities with a belief vector. Bian et al. [16] proposes an approach for generating adaptive learning paths by creating a learner-centred concept map and using an immune algorithm to select learning objects for the optimal path. Smith [189] investigated preservice teachers' perceptions of adaptive learning programs for K-8 mathematics classrooms, finding that such programs were beneficial but required careful consideration when integrating them into teaching practice. Idrobo and Davidson-Hunt [84] examines the adoption of technology to appropriate an ecologically constrained resource within the context of a restructuring fisheries sector using the conceptual lenses of adaptive learning and practice. Hou and Fidopiastis [74] reviews the evolution of learning theories and guides designers of intelligent adaptive learning systems for individualised learning, illustrated by a customised intelligent tutoring system for improvised explosive device disposal operator training. Pedan [160] proposed a method for developing adaptive tutoring software based on competence-based learning principles. Vyshnevska [210] proposes a computer-based adaptive learning system developed on fuzzy logic principles. The teacher-like system is based on the student model, which consists of a stable (student's psychological features measured before training) and a variable (student's development during training). The correction of the learning curve is based on both the model of student and management goals.

Seven papers, 1 DSc thesis, 8 PhD theses and three technical reports related to applying adaptive learning and analytics in various educational settings and systems, including MOOCs, school education, and technology-enhanced learning projects. Li, Zhao and Gan [111] focuses on applying adaptive learning in MOOCs and proposes a customised MOOC learning model that includes a personalised course map and an adaptive MOOC learning system to improve pedagogical effectiveness and reduce the high attrition rate of students in MOOCs. Mavroudi, Giannakos and Krogstie [124] reviews recent publications on learning analytics applications in adaptive learning and identifies a lack of studies on school education and non-STEM topics and a trend of considering more complex student behaviours. Welsh and Uys [216] discussed the reconfiguration of institutional learning analytics at Charles Sturt University to create an Adaptive Learning and Teaching program that integrates analytics and feedback to personalise online learning. Angelaccio and Buttarazzi [12] presents EduSHARE, a P2P distributed learning system based on a group-based file sharing extended with dynamic test modules aimed to be integrated into a course to improve interactivity between several actors playing in a common lesson scenario. Di Mascio et al. [41] describes the user-centered design approach used to design and develop TERENCE, a technology-enhanced learning project aimed at stimulating inference-making about stories for poor comprehenders aged 7-11. Hu and Huang [76] presents an approach for designing a test bank using the grasp degree towards concepts mechanism to record students' learning performance and provide adaptive guides for learners. Cui et al. [33] described using item response theory to measure student ability and item difficulty, using actual data to evaluate the Squirrel AI Learning System. Fedoruk [58] proposed a set of models, e.g., the model of a student, the model of class, the models of adaptive knowledge control (algorithmic and fuzzy), and a model of individual adaptive learning trajectory technology. For the first time, proposed models have been used to develop the adaptive distance learning system. Yurchenko [222] proposes the structural and logical charts of learning and knowledge control based on semantic connections between the educational material blocks and test questions. A method author for determining the priority of blocks of educational material and a method for assessing the adequacy of the complexity level of knowledge control questions, taking into account the final specialist's assessment and adaptive models for adjusting complexity in real-time. Martynova [120] developed methods that use semantic functional networks for the representation of knowledge on the tasks of the learning and control process, as well as the situational method of learning and control of knowledge acquisition for control tasks and methods of classification of situations, criteria for managing the learning process and testing in the elimination of critical situations. For the formalised description of the functions of adaptive management, the models of knowledge about determining the trainees' category and the management events were developed. Tonkonohyy [199] develops decision-making information technology using a quantitative assessment of the level of assimilation of students' knowledge as complex objects. A method for identifying and collecting SCORM-based educational content for preparing an electronic course in the adaptive learning system is proposed by Kyrychenko [104]. Mazurets [127] proposes a method for automated structuring of learning materials and a method for generating test questions automatically from the learning materials that can be used for adaptive knowledge control. Osadchyy [156, 157] introduce an immersive techniques into adaptive system of blended learning [156]. As a result, the adaptive information system for individual professional training in blended learning conditions was developed [157]. Ananta [9] proposes an adaptive hypermedia learning system that initially limits students' choices until they have mastered fundamental concepts. The system analyses learner responses, and once key concepts have been learned, learners are allowed increased access to a greater range of learning materials and options. Jiang [88] has focused on applying adaptive testing techniques to the learning environment. The researcher proposes a new online learning system with a Bayesian algorithm that computes item and person parameters on the fly. Fielder [60] proves that a computer adaptive test, as compared to using the entire test, is more effective. The significant finding of this study indicates that with a well-targeted audience, there are substantial correlations between the two test versions and that the computer adaptive test is significantly quicker to take than the computer-administered full test. Mehigan [129] investigates how biometric technologies, in particular accelerometer and eye-tracking technologies, could effectively be employed within the development of mobile learning systems to facilitate the needs of individual learners. The author provides recommendations for developers to create adaptive mobile learning systems using biometric technology as a user interaction tool within mobile learning applications. Rudnitska [175] proposes a conceptual model of an adaptive system of continuing education for smart industries and a method for building an individual learning trajectory that allows student-based management of learning, taking into account their competencies, evaluation of the effectiveness of the planned activities, and modernisation of training content by EdTech providers.

The papers from the cluster of adaptive learning systems and education computing are related to three main topics:

1) *integrating learning styles into adaptive e-learning hypermedia systems*: developing computer-based science learning media, proposing adaptive learning frameworks, exploring adult constructive-developmental theory, and recommending learning paths based on learners' knowledge and course topics;
2) *intelligent tutoring systems and adaptive learning approaches in mathematics education*: highlighting their effectiveness, benefits, and the design of personalised learning experiences using different methods.
3) *application of adaptive learning and analytics in various educational settings and systems*, including MOOCs, school education, and technology-enhanced learning projects: related papers demonstrate the potential of adaptive learning to personalise learning experiences, improve pedagogical effectiveness, and reduce attrition

rates.

Overall, the papers reflect the growing interest in using adaptive learning and analytics in education and the need for further research.

1.2.4. A cluster of learning and education research

A cluster of learning and education research (in yellow colour) represented by 23 papers.

Fifteen papers, one PhD thesis, and one technical report cover various topics related to learning and education, including teacher-centred instruction, logistical support for learners, learning styles, flipped learning, personalised-adaptive learning environments, etc. Ziimpe [226] discusses introducing adaptive learning into the new canonical macroeconomic model and how it affects the stability of monetary policy rules. Mccaslin and Burross [128] presents research on teacher-centred instruction and individual differences among students within a sociocultural perspective. Nasr-Eddine, Zaidi and Eddine [140] proposes an approach to improve logistical support in learning for learners of all ages. Huang et al. [77] explores using mobile agents to assist students in virtual learning environments, focusing on reducing the burden on teachers. Covington [32] discusses the current understanding of the cognitive, motivational, and situational determinants of school achievement and identifies gaps in knowledge. Sandman [176] reports on a study that examined business students' learning styles and found that their styles may depend more on the course than their major. Nurjanah [147] proposes a collaborative authoring approach for creating adaptive learning systems and presents the results of qualitative and quantitative experiments validating the approach. Levy [108] describes a book that presents the principles of classical and instrumental conditioning and their applications in understanding the human condition. Daniel, Cano and Gisbert Cervera [34] discusses MOOCs' challenges and proposes five dimensions for understanding their future. Dong and Sharma [43] explores the combination of the flipped classroom model and adaptive learning in medical education. Yetişir and Ceylan [220] adapted a scale to measure students' attitudes toward science learning in Turkish and found it valid and reliable. Tashiro et al. [198] explores the development and evaluation of a personalised adaptive learning environment for computer information technology education. Torrano and González-Torres [200] reports on the initial validation study of motivational scales for secondary education students in Spain. Mei, Guo and Li [130] describes designing a multimedia-based English pronunciation learning system with a self-adaptive learning mode. Laitinen, Piazza and Stenvall [106] presented the qualitative study that explores learning processes in smart city organisations in Helsinki and Catania. Elbrekht [47] highlights the transformation of the management culture of school principals. According to Elbrekht [47], the technology of adaptable management is a transformational cycle of planning (aims, goals, and tasks), modelling (algorithms, criteria of efficiency, prediction), management (communication and collaboration), monitoring (measurement, assessment, evaluation), correction (reflexly and self-reflexly, SWOT analyses, etc.). Bobrova [17] proposes a set of models, e.g., the general model of adaptive management of the professional development of scientific and pedagogical workers and the model of adaptive management of the student's independent work.

Five papers discuss several studies related to adaptive learning in medical education. Menon et al. [131] identified factors associated with persistent use of the Osmosis platform by US medical students. Huffman et al. [80] investigated using data from Human Dx to assess diagnostic reasoning skills and deliver tailored content. Bouzenada, Boissier and Zarour [19] proposed a multiagent system for adaptive learning based on learning styles and domain knowledge. Tackett et al. [196] examined crowdsourcing for multiple-choice questions in medical education. Finally, Sharma and Jordan [182] discussed the potential of adaptive learning in medical education in the UK.

Three papers, 1 PhD thesis and one technical report related to the implementation and effectiveness of adaptive learning technology. Kakish and Pollacia [95] discusses using adaptive learning technology in an Information Technology course to improve student scores, pass rates, and retention levels. Kakish, Robertson and Jonassen [96] presents a study on student and instructor perceptions of adaptive learning technology in a computing course, finding that it was viewed as a beneficial addition to the course. Kellman and Krasne [100] discusses using adaptive learning technology in combination with perceptual learning interventions to improve medical learning and performance. Seriakov and Shcheholkova [179] propose an automated method of determining the structure of a student's cognitive model. Pikulyak [165] proposes a method of assessment of results of knowledge test control based on multiset theory and information quantification.

After reviewing the selected articles from the learning and education research cluster, it is clear that adaptive learning technology is becoming increasingly popular in the education sector, particularly in macroeconomics, information technology, and medical education. The articles discussed various approaches to adaptive learning, including personalised adaptive learning environments, collaborative authoring, and mobile agents. The potential benefits of using adaptive learning technology include improving student scores, pass rates, and retention levels and reducing the burden on teachers.

When implementing adaptive learning systems, the studies also highlighted the importance of considering individual differences among students, including their learning styles and attitudes towards learning. Moreover, several studies emphasised the need for further research to identify the cognitive, motivational, and situational determinants of school achievement and validate motivational scales for different educational contexts.

Finally, the studies discussed the challenges facing adaptive learning technology, such as ensuring the validity and reliability of measures and addressing ethical and privacy concerns. Despite these challenges, the potential of adaptive learning technology to improve educational outcomes and enhance the learning experience for students and teachers alike is promising.

1.2.5. A cluster of personalised learning

A cluster of personalised learning (in violet colour) presented by five papers and 3 PhD theses discusses various aspects of adaptive learning as a highly intelligent learning resource service model that provides learners with personalised learning paths and resources. Peng, Ma and Spector [162] introduces personalised adaptive learning, a new teaching method enabled by a smart learning environment that promotes the development of personalised and adaptive learning. Liu et al. [117] emphasises the need for evidence-based research to understand how user behaviour patterns can be used to design effective adaptive learning systems. Zhao and Wang [224] focuses on the three core modules of the adaptive learning system, including the knowledge network model, cognitive level model, and adaptive recommendation model, which improve learning by integrating user-specific behavioural characteristics such as learning habits and knowledge capacity. Davis et al. [36] shares experiences exploring and implementing adaptive learning for first-year pharmacy students. Finally, Liu et al. [118] investigates the impact of an adaptive learning intervention to provide remedial instruction in various content areas to first-year students entering a pharmacy professional degree program. The study findings highlight the importance of design in adaptive learning and emphasise the need to consider affective factors such as motivation in adaptive learning. Kuzikov [103] develops the model of the adaptive construction of an individual learning trajectory and a criterion for evaluating the effectiveness of the distance learning system. Andrukhiv [11] develops an adaptive method of forming a list of recommended literature for academic disciplines, which includes an assessment of the relevance of the list items. Shemshack [184] investigated personalised adaptive learning, teacher education, and self-efficacy to determine if personalised adaptive teacher education can increase self-efficacy. The researcher suggested that teachers with higher self-efficacy tend to stay in the teaching profession longer. As a result, it was found that teachers' self-efficacy increases with more training, support, and resources. The teacher's training curriculum introduced components of personalised adaptive learning to provide support/help at the right time for teachers to improve their self-efficacy.

All reviewed works from the cluster of personalised learning are:

- focus on the benefits and challenges of adaptive learning, which is a form of personalised learning that uses technology to provide learners with customised learning experiences based on their individual needs and abilities;
- explore various aspects of adaptive learning, such as the design and implementation of adaptive learning systems, the role of user behaviour patterns in designing effective adaptive learning systems, and the impact of adaptive learning interventions on student learning outcomes;
- highlight the importance of evidence-based research and design in developing and implementing adaptive learning systems.

1.3. Conclusion

A bibliometric review helped determine the main research directions in adaptive learning. A cluster analysis distinguished five clusters: a cluster of general concepts of adaptive learning in e-learning systems, a cluster of educational technology, a cluster of adaptive learning systems and education computing, a cluster of learning and education research, and a cluster of personalised learning. This allowed the grouping of the reviewed scientific papers and PhD theses in a literature review to highlight the main themes related to adaptive learning.

As a result of the conducted research, it was determined that

- All articles reveal certain aspects of adaptive or personalised learning.
- An attempt to divide the clusters into subclusters revealed that the clusters are closely connected.
- Outlined topics that are most closely related to adaptive learning: AI technologies in the development of adaptive learning systems, personalised education, learning styles, approaches in adaptive learning systems, development and use of adaptive learning systems, implementation and effectiveness of adaptive learning technologies, including eye-tracking, and physiological measurements to enhance the personalisation and effectiveness of learning.

Furthermore, the bibliometric review highlighted the dynamic and interconnected nature of research in adaptive learning. The analysis revealed that the clusters identified are not isolated entities but interconnected domains, indicating the multidimensional nature of adaptive learning research. This suggests that advancements in one cluster can have implications and contribute to developments in other clusters, fostering a holistic understanding of adaptive learning.

The findings of the cluster-based literature review underscored the importance of AI technologies in the development of adaptive learning systems, as well as the significance of personalised education and catering to individual learning styles. The identified topics emphasised various approaches within adaptive learning systems, including their development, implementation, and effectiveness. As Ukraine pursues educational excellence, embracing adaptive learning systems and personalised approaches will play a pivotal role in fostering a highly effective and dynamic education system for the future.

The main results of the first chapter are presented in scientific works [54–56].

CHAPTER 2

Research methodology

2.1. Introduction

According to the results from the literature review, one of the further research prospects is the adaptive learning systems based on learning management systems (LMS) like Moodle. Osadchyi [155] defined ways of using LMS Moodle for individualization and personalization of education in higher education institutions. Moodle is not positioned by the developers as an adaptive learning system. Still, the growing popularity of adaptive learning technology has prompted Moodle developers and other programmers to improve it [155, p. 37].

According to [155, p. 37], LMS Moodle provides the following tools to implement an individual approach:

1. Tools for forming the training route by imposing the necessary restrictions on the training elements (tracking the performance of the element, tracking the level of assessment).
2. Multi-criteria evaluation tools (Evaluator's Handbook, Rubrics), which consider the material's complexity.
3. Tools that allow you to implement the multivariate presentation of educational information within the framework of a single distance course.
4. Formation of a presentation profile for each group of listener's educational material.

Moodle offers several features that can support a personalized learning experience:

1. Modular course structure: content can be broken down into smaller, bite-sized modules, allowing students to learn at their own pace and focus on specific areas

they need to improve.

2. Variety of activities and resources: Moodle allows instructors to incorporate diverse learning materials like videos, quizzes, and interactive activities, catering to different learning styles and preferences.
3. Adaptive feedback and assessments: Moodle can be integrated with tools that provide personalized feedback based on student performance, guiding them toward a more profound understanding.
4. Interactive learning tools: Features like forums and discussions enable peer-to-peer learning and collaboration, fostering engagement and community.

Thus, Moodle LMS can be used as an adaptive learning system in a particular context.

Many works are devoted to learning analytics and machine learning in Moodle LMS [178]. Thus, Abuzinadah et al. [1], Kaensar and Wongnin [94], Perez-Suay et al. [163] used educational data mining methods (machine learning-based system) to predict students' academic performance.

Some plugins for adaptive learning were developed in the last years (Krahn, Kuo and Chang [102], Moreno-Marcos et al. [138], Quispe-Pari et al. [169], Tamo-Vargas et al. [197]) using both supervised and unsupervised machine learning techniques (Vásquez-Bermúdez, Aguirre-Munizaga and Hidalgo-Larrea [211]).

Thus, recent developments add value to the statement on using Moodle LMS as an adaptive learning system.

According to [164], the learning theory underlies Moodle's development is the social constructionist pedagogy that united constructionism, social constructivism, and active learning.

According to [92, p. 156], "in constructivism knowledge is constructed in the mind of the learner ... when they connect what they already know ... to ... activities they have experienced. Active engagement, inquiry, problem-solving and collaboration characterize this type of learning with the teacher acting as a guide, facilitator and co-explorer who encourages the students to question, challenge and formulate their own ideas, opinions and conclusions. Social constructivism, a sociocultural attribute of constructivism, asserts that social interaction promotes reflection, the development of communication skills, deep conceptual understanding and exposure to different ideas." The findings Jordan [92] showed that the activities provided by Moodle do foster a constructivist approach to learning and can provide students with the types of learning experiences they desire. However, their effectiveness is, to a large extent, dependent on the teacher's role in designing and directing the online learning experience.

The relationship between learning and student outcomes, often measured through grades or marks, has been a central focus in education for centuries. Traditionally, this relationship has been conceptualized as a linear progression:

$$\text{Learning} \rightarrow \text{Assessment} \rightarrow \text{Grades/Marks}$$

This model assumes a uniform learning experience for all students, followed by a standardized assessment determining their grades. However, this simplistic approach fails to acknowledge individuals' diverse needs and learning styles, potentially hindering student engagement and affecting performance.

To address these limitations, the concept of adaptive learning has emerged, aiming to personalize the learning experience for each student. This approach can be summarized as follows:

$$\text{Adaptive Learning} \rightarrow \text{Personalized Learning Experience} \rightarrow$$
$$\rightarrow \text{Higher Engagement} \rightarrow \text{Higher Grades/Marks}$$

This model proposes that technology and data-driven insights can tailor learning environments to individual needs and preferences. By creating a personalized learning experience, students are more likely to become engaged with the material, leading to deeper understanding and, ultimately, higher grades or marks. In this context, Moodle is a potential platform for fostering better student outcomes through adaptive learning practices.

In Kryvyi Rih State Pedagogical University (Ukraine), the following regulations [170, 171] define the recommended Moodle course structure and grades that can be united into the five constructs:

1. **Information**: The course's full name must begin with a code that reflects the form of education (full-time, part-time) and educational level – bachelor's or master's. Also provided is the semester in which the discipline is taught and the teachers [171, p. 6, 9, 13], and course status (normative or optional academic discipline). The following data [171, p. 13-14] can be extracted from the course abstract: 1) *Form of education*, 2) *Educational level*, 3) *Semester* (1 to 8), 4) *Status*, and 5) *Number of teachers*, which together form the construct "Information".
2. **Resources**: "Mandatory elements of the course are: general information about the academic discipline [*Label*] ...; information about the teacher ... – in the form of the *Page* resource type; *URL* to the working program of the academic discipline ... and the syllabus [171, p. 14]. "Course may also contain: ... *Books*" [171, p. 16] Resources not regulated by the regulation but can be used in courses: *Folder* and *File*. All these 6 resources together form the construct "Resources".
3. **Activities**: "The components of the courses are mainly drawn up in the form of: *Assignment*, *Quiz*, *SCORM*, *Glossary*, *Lesson*, *Feedback*"[171, p. 16], *H5P*, *HotPot*, *Survey*, *Database*, *Choice*, *Visiting*,*Wiki*, *LTI External tool activity*, *Workshop*. All these 15 activities together form the construct "Activities".

4. **Communication**: "*Forum*, in particular, announcements (news forum) provides an announcement of events, notification of changes in course, etc.; a forum for questions to the teacher – provides communication between the teacher and students regarding problems, questions that arise during the study of the discipline" [171, p. 16]. *Chat* can also be used for this. These 2 activities form the construct "Communication".
5. **Assessment**: "The final assessment of the student's academic performance is determined on a 100-point scale, the ECTS scale and the national grading scale " [170, p. 4]. All these scales are closely connected; therefore, a 6-grade modified ETCS scale can be used: A (the highest mark), B, C, D, E (the lowest passing mark), F/FX (not passed).

According to the social constructionist pedagogy, these constructs can be closely connected:

- *Information* is the single entry point to each course. Therefore, other constructs are connected with it.
- *Resources* are used by students to build understanding and to prepare for *Activities*.
- *Activities* are used by teachers to involve students in problem-solving, exploration, and hands-on experiences using *Communications* like online communities and group work.
- *Communication* fosters interactions and knowledge acquisition through discussions and collaborative projects to enhance understanding.
- *Assessment* measures observable outcomes and focuses on understanding how students construct knowledge and apply it in real-world contexts.

2.2. Research objective

The research objective was formulated after examining the potential link between the constructs.

This study aims to determine whether the use of Moodle (its resources and activities) contributes to the personalization of learning, namely, whether the content of a course in Moodle with various resources and activities is associated with student learning outcomes.

2.3. Research questions

This objective can be restated in the terms defined above as follows:

1. How interconnected are the Moodle internal constructs like *Information*, *Resources*, *Activities*, and *Communication*?
2. How connected are the Moodle internal constructs (*Information*, *Resources*, *Activities*, and *Communication*) and external *Assesment* construct?

The conceptual model based on the suggestions shown in figure 2.1 and the hypotheses for the research study have been developed.

2.4. Hypotheses

H1: There is a significant relationship between the *Information* construct and *Communication* construct in the Moodle course.

H2: There is a significant relationship between the *Communication* construct of the Moodle course and the external *Assesment* construct.

H3: There is a significant relationship between the *Resources* construct and *Activities* construct in the Moodle course.

H4: There is a significant relationship between the *Resources* construct and *Information*

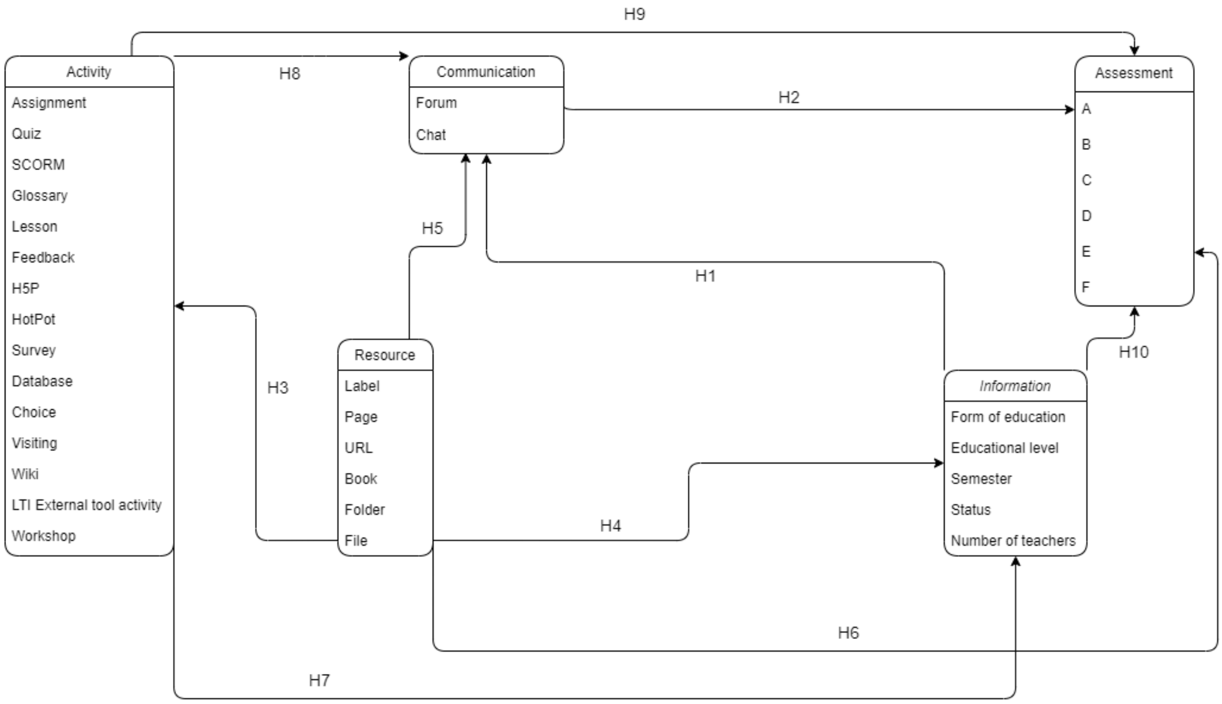


Figure 2.1: Conceptual model.

construct in the Moodle course.

H5: There is a significant relationship between the *Resources* construct and *Communication* construct in the Moodle course.

H6: There is a significant relationship between the *Resources* construct of the Moodle course and the external *Assesment* construct.

H7: There is a significant relationship between the *Activities* construct and *Information* construct in the Moodle course.

H8: There is a significant relationship between the *Activities* construct and *Communication* construct in the Moodle course.

H9: There is a significant relationship between the *Activities* construct of the Moodle course and the external *Assesment* construct.

H10: There is a significant relationship between the *Information* construct of the Moodle course and the external *Assesment* construct.

2.5. Research design

The study employed a quantitative approach to examine and test the proposed hypotheses. Specifically, the Structural Equation Modeling - Partial Least Squares (SEM-PLS) technique was utilized to create the model and investigate the strength and reliability of the relationships between the constructs.

The SEM-PLS approach is a powerful statistical method that combines factor analysis and path analysis, allowing researchers to examine the relationships between multiple independent and dependent variables simultaneously [72, p. 96]. This technique is instrumental when dealing with complex models involving latent variables which cannot be directly observed or measured.

The data analysis and model estimation were performed using Adanco, a specialized software package for SEM-PLS modelling [71]. Adanco is known for its efficient and robust algorithms, enabling researchers to process large datasets quickly and accurately. This software facilitated the estimation of the model parameters, assessment of the measurement model, and evaluation of the structural model [87], thereby providing insights into the relationships among the constructs under investigation.

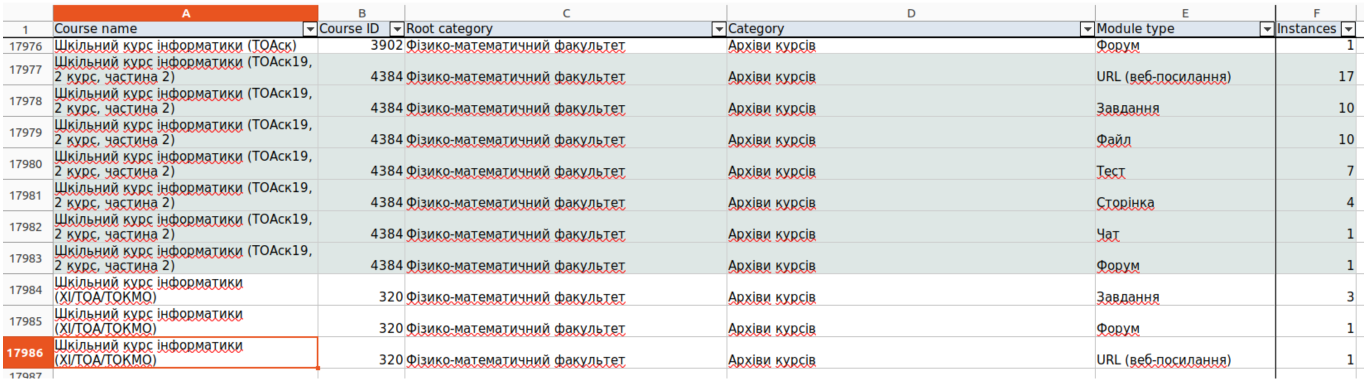
2.6. Data collection

Data from Kryvyi Rih State Pedagogical University (KSPU) were used for the empirical analysis. The collection and digitization of student performance data across all university specialities for the 2020-2021 (winter and summer sessions) and 2021-2022 (winter session) academic years were approved by the KSPU rector's decision and the university's ethical committee on January 26, 2024.

The Course module instances report plugin [207] was installed and used to export a spreadsheet with the course data (figure 2.2):

- *Course name* – the original course title from the KSPU Moodle site (https://moodle.kdpu.edu.ua);
- *Course ID* – unique number (3..10062) identified the course; it can be useful for courses with identical titles;
- *Root category* – the course root category used in KSPU. Each category has been encoded with a unique number as follows:
    1. Faculty of Natural Sciences (Природничий факультет)
    2. Faculty of Psychology and Pedagogics (Психолого-педагогічний факультет)
    3. Faculty of Geography, Tourism and History (Факультет географії, туризму та історії)
    4. Faculty of Pedagogical Education (Факультет педагогічної освіти)
    5. Faculty of Foreign Languages (Факультет іноземних мов)
    6. Faculty of Arts (Факультет мистецтв)
    7. Faculty of Ukrainian Philology (Факультет української філології)
    8. Faculty of Physics and Mathematics (Фізико-математичний факультет)
    9. All-university departments and divisions (Загальноуніверситетські кафедри та відділи)
- *Category* – additional course category further ignored;
- *Module type*s: H5P, HotPot, SCORM, URL, Survey, Database, Choice, Visiting, Wiki, Glossary, Assignments, Feedback, LTI External tool activity, Book, Label, Workshop, Page, Folder, Quiz, Lesson, File, Forum, Chat;
- *Instances* – the number of module instances used in the course.

The total number of records received on April 07, 2024, was 25595. After receiving the list of all courses, courses with a non-educational purpose (surveys, service, etc.) and courses taught in graduate school were removed from the general list. The total number



	A	B	C	D	E	F
1	Course name	Course ID	Root category	Category	Module type	Instances
17976	Шкільний курс інформатики (ТОАск)	3902	Фізико-математичний факультет	Архіви курсів	Форум	1
17977	Шкільний курс інформатики (ТОАск19, 2 курс, частина 2)	4384	Фізико-математичний факультет	Архіви курсів	URL (веб-посилання)	17
17978	Шкільний курс інформатики (ТОАск19, 2 курс, частина 2)	4384	Фізико-математичний факультет	Архіви курсів	Завдання	10
17979	Шкільний курс інформатики (ТОАск19, 2 курс, частина 2)	4384	Фізико-математичний факультет	Архіви курсів	Файл	10
17980	Шкільний курс інформатики (ТОАск19, 2 курс, частина 2)	4384	Фізико-математичний факультет	Архіви курсів	Тест	7
17981	Шкільний курс інформатики (ТОАск19, 2 курс, частина 2)	4384	Фізико-математичний факультет	Архіви курсів	Сторінка	4
17982	Шкільний курс інформатики (ТОАск19, 2 курс, частина 2)	4384	Фізико-математичний факультет	Архіви курсів	Чат	1
17983	Шкільний курс інформатики (ТОАск19, 2 курс, частина 2)	4384	Фізико-математичний факультет	Архіви курсів	Форум	1
17984	Шкільний курс інформатики (ХІ/ТОА/ТОКМО)	320	Фізико-математичний факультет	Архіви курсів	Завдання	3
17985	Шкільний курс інформатики (ХІ/ТОА/ТОКМО)	320	Фізико-математичний факультет	Архіви курсів	Форум	1
17986	Шкільний курс інформатики (ХІ/ТОА/ТОКМО)	320	Фізико-математичний факультет	Архіви курсів	URL (веб-посилання)	1

Figure 2.2: Spreadsheet with the course data (fragment).

of records after removal is 17985.

The new spreadsheet was built based on the exported non-removed data (table 2.1). The total number of courses in the spreadsheet is 3600. The information block was also added (the data were extracted manually from the course annotations in Moodle), including the form of education, educational level, semester, status, and number of teachers.

After that, the relevant courses with student grades were filled in. This process was completed, and the number of courses was reduced to 985, as new courses not taught from 2020 to 2022 were excluded.

Table 2.1: Data fields.

Indicator	Description
Course ID	unique number (3..10062) identified the course
Category	the course root category identifier (1..9)
Form of education	1 – course for fulltime education only, 2 – course for part-time education only, 3 – course for both full-time and part-time education
Semester	semester in which course is ended (1..8)
Status	1 – normative course, 2 – optional course
Educational level	1 – undergraduate level (course for bachelor students), 2 – graduate level (course for master students)
Number of teachers	Number of teacher staff related to the course (1..9)
H5P	Number of H5P activity instances used in the course (0..3)
HotPot	Number of HotPot activity instances used in the course (0..3)
SCORM	Number of SCORM activity instances used in the course (0..15)

Continued on next page

Table 2.1 – continued from previous page

Indicator	Description
URL	Number of URL resource instances used in the course (0..83)
Survey	Number of Survey activity instances used in the course (0..1)
Database	Number of Database activity instances used in the course (0..9)
Choice	Number of Choice activity instances used in the course (0..1)
Visiting	Number of Visiting activity instances used in the course (0..3)
Wiki	Number of Wiki activity instances used in the course (0..11)
Glossary	Number of Glossary activity instances used in the course (0..5)
Assignments	Number of Assignments activity instances used in the course (0..142)
Feedback	Number of Feedback activity instances used in the course (0..2)
LTI External tool activity	Number of LTI External tool activity instances used in the course (0..1)
Book	Number of Book resource instances used in the course (0..20)
Label	Number of Label resource instances used in the course (0..117)
Workshop	Number of Workshop activity instances used in the course (0..25)
Page	Number of Page resource instances used in the course (0..53)
Folder	Number of Folder resource instances used in the course (0..22)
Quiz	Number of Quiz activity instances used in the course (0..93)
Lesson	Number of Lesson activity instances used in the course (0..17)
File	Number of File resource instances used in the course (0..54)
Forum	Number of Forum communication activity instances used in the course (0..13)
Chat	Number of Chat communication activity instances used in the course (0..1)
A	Number of A marks among the course final grades
A%	Percent of A marks among the course final grades
B	Number of B marks among the course final grades
B%	Percent of B marks among the course final grades
C	Number of C marks among the course final grades
C%	Percent of C marks among the course final grades
D	Number of D marks among the course final grades
D%	Percent of D marks among the course final grades
E	Number of E marks among the course final grades
E%	Percent of E marks among the course final grades
F	Number of Fx and F marks among the course final grades
F%	Percent of Fx and F marks among the course final grades

Prepared dataset from 985 observations without missing values available at Zenodo [52].

2.7. Model construction

The prepared dataset [52] was imported in Adanco 2.4. Then, 5 constructs were created from indicators listed in the table 2.1 as described in section 2.1 (table 2.2).

Table 2.2: Composite model constructs.

Name	Type	Indicators
Information	Emergent	Form of education, Educational level, Semester, Status, Number of teachers
Resources	Emergent	Label, Page, URL, Book, Folder, File
Activities	Emergent	Assignment, Quiz, SCORM, Glossary, Lesson, Feedback, H5P, HotPot, Survey, Database, Choice, Visiting, Wiki, LTI External tool activity, Workshop
Communication	Emergent	Forum, Chat
Assessment	Latent	A, B, C, D, F

In structural equation modelling, constructs can be classified into emergent and latent. The choice between emergent and latent constructs depends on the nature of the variables.

Emergent constructs, or composite or formative constructs, are formed by combining or "causing" a set of observed indicators or variables. In other words, the indicators collectively define and cause the construct. The indicators are not necessarily expected to be correlated, and the construct is a linear combination of these indicators. In table 2.2, the following constructs are specified as emergent: Information, Resources, Activities, and Communication. The choice of emergent type for these constructs is appropriate because the indicators are assumed to define or cause the construct rather than being manifestations or effects of the construct.

Latent or reflective constructs are unobserved or unmeasured variables that are assumed to cause or influence a set of observed indicators or variables. In table 2.2, the

Assessment construct is specified as latent. A latent type for the Assessment construct is appropriate because the indicators (A, B, C, D, F) are assumed to be reflections or manifestations of the underlying assessment construct. In other words, the Assessment construct is assumed to cause or influence the observed indicators.

The source of indicators for emergent constructs is the data exported directly from Moodle (observed in Moodle). The source of indicators for latent construct is the students' performance data digitized from the grade sheets (unobserved in Moodle). Emergent constructs are formed by the combination of indicators observed in Moodle, while latent construct is assumed to cause or influence the observed indicators.

The last step was setting the linear relationship between constructs according to the hypothesis (figure 2.3, table 2.3).

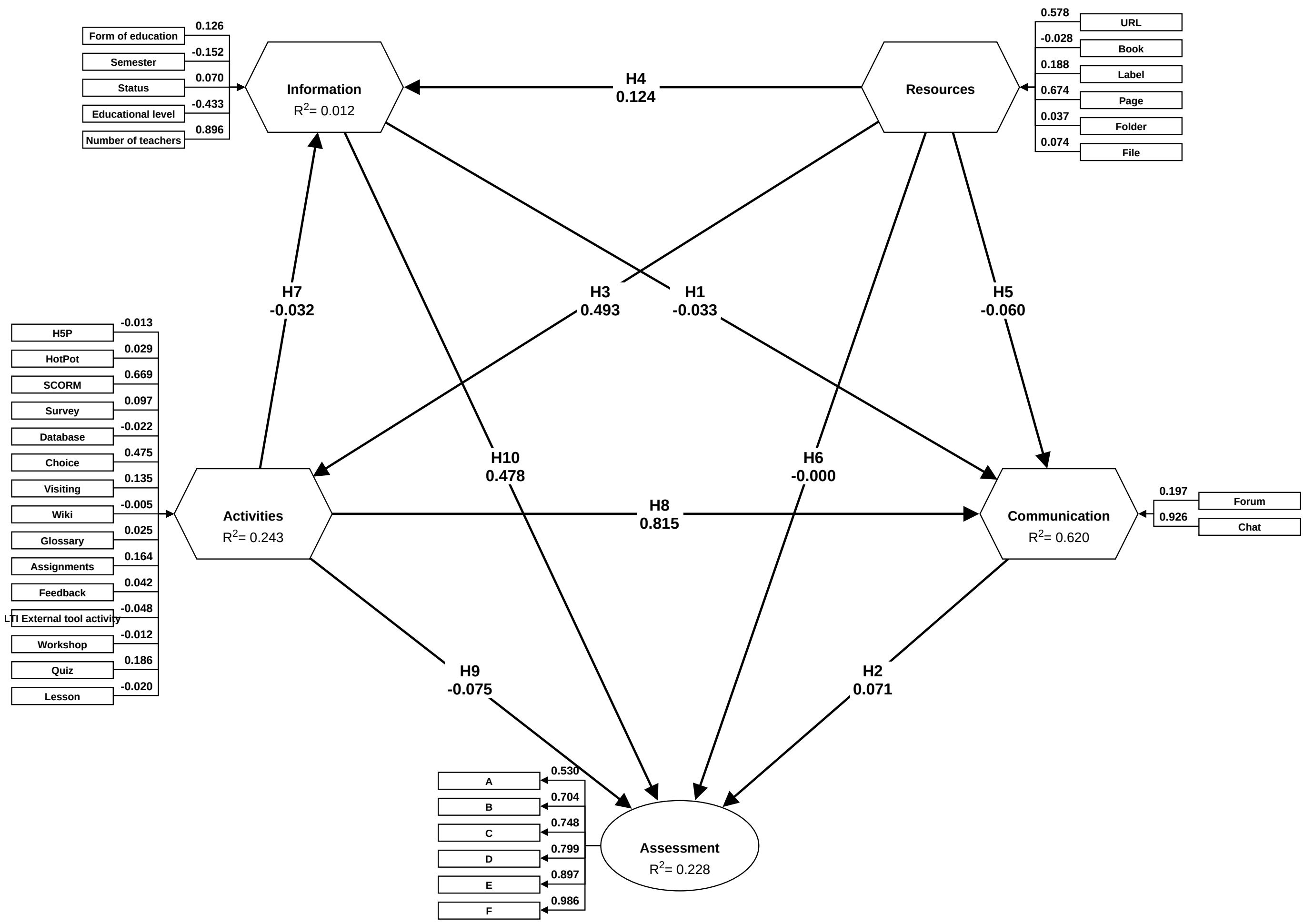


Figure 2.3: Conceptual model in Adanco 2.4.

Table 2.3: Design matrix.

Independent variable	Dependent variable				
	Information	**Activities**	**Resources**	**Comunication**	**Assessment**
Information	0	0	0	1	1
Activities	1	0	0	1	1
Resources	1	1	0	1	1
Communication	0	0	0	0	1
Assessment	0	0	0	0	0

2.8. Conclusion

In this chapter, we employ a quantitative approach using Structural Equation Modeling — Partial Least Squares (SEM-PLS) to investigate the relationships between various constructs derived from Moodle LMS and student assessment outcomes. The conceptual model was developed based on the social constructionist pedagogy underlying Moodle's development and the university regulations regarding Moodle's course structure and assessment.

The model comprised five constructs: Information, Resources, Activities, Communication, and Assessment. The Information, Resources, Activities, and Communication are emergent constructs formed using indicators directly observed from Moodle course data, while the Assessment construct was a latent construct reflecting student performance data.

The main results of the second chapter are presented in scientific work [52].

CHAPTER 3

Results and discussion

3.1. Introduction

Building upon the literature review established in chapter 1 and the research methodology outlined in chapter 2, this chapter describes the findings from the data analysis. This investigation aimed to explore the interconnectedness within the Moodle learning environment and its potential impact on student learning outcomes.

Specifically, we sought to address two key research questions:

RQ1: How interconnected are the Moodle internal constructs like Information, Resources, Activities, and Communication? This question investigated the relationships between the core elements of a Moodle course, aiming to understand how these components interact and potentially influence each other.

RQ2: How connected are Moodle's internal constructs (Information, Resources, Activities, and Communication) and external Assessment? This question focused on the connection between Moodle's internal environment (resources, activities, information, and communication) and the external construct of student assessment.

By examining these relationships, we aimed to determine whether the design and use of Moodle (specifically, the variety of resources and activities) contributes to the personalization of learning. In other words, we investigated if the richness of content within a Moodle course, encompassing resources, activities, and communication, is associated with improved student learning outcomes as measured by external assessments.

The following sections will present the findings from the data analysis, addressing each research question and interpreting the results in the context of initial hypotheses.

Hypotheses that have been put forward:

H1: There is a significant relationship between the *Information* construct and *Communication* construct in the Moodle course.

H2: There is a significant relationship between the *Communication* construct of the Moodle course and the external *Assessment* construct.

H3: There is a significant relationship between the *Resources* construct and *Activities* construct in the Moodle course.

H4: There is a significant relationship between the *Resources* construct and *Information* construct in the Moodle course.

H5: There is a significant relationship between the *Resources* construct and *Communication* construct in the Moodle course.

H6: There is a significant relationship between the *Resources* construct of the Moodle course and the external *Assessment* construct.

H7: There is a significant relationship between the *Activities* construct and *Information* construct in the Moodle course.

H8: There is a significant relationship between the *Activities* construct and *Communication* construct in the Moodle course.

H9: There is a significant relationship between the *Activities* construct of the Moodle course and the external *Assessment* construct.

H10: There is a significant relationship between the *Information* construct of the Moodle course and the external *Assessment* construct.

3.2. Results

3.2.1. Algorithm settings

We used the ADANCO to build a model and trained the model [51] with the following settings:

- The *criterion to stop* the optimization process was $1 \cdot 10^{-6}$: when the improvement in the model's fit falls below this threshold, the optimization process stops.
- The *maximum number of iterations* allowed for the optimization process was 2000. However, the iterative algorithm converges after 18 iterations (see iteration history at the https://ssemerikov.github.io/Fadieieva/#technical_output), so the process doesn't reach this limit.
- The ADANCO algorithm's internal weighting scheme was factor-based (*factorial scheme*). This scheme used the correlation between variables directly (an alternative centroid scheme used only the sign of the correlation function, which was rougher in general).
- We don't use missing value treatment like casewise deletion because the original data *don't contain missing values* in any variables.
- We use resampling techniques (e.g., bootstrapping for inference statistics) to estimate the sampling distribution of a statistic Henseler [71, p. 15-17].
- The fit of the main development model ($\mathrm{main.de.adancodevelopment.model}$) was evaluated.

3.2.2. The goodness of fit of model

Table 3.1 contains goodness-of-fit statistics for the model.

Table 3.1: Goodness of model fit.

	Value	**HI95**	**HI99**
$SRMR$	0.0546	0.0844	0.0924
d_{ULS}	1.7755	4.2361	5.0810
d_G	0.8083	240.4797	346.0613

The standardized root mean squared residual $SRMR$ measures the discrepancy between the observed correlations and those predicted by the model. A low SRMR (0.0546) indicates a good fit.

Unweighted least squares distance d_{ULS} measures the discrepancy between the observed and reproduced pairwise distances among the samples. It reflects how well the model reproduces the distances between the samples. A low value (1.7755) indicates a good fit.

Geodesic discrepancy d_G is another approach to quantify how strongly the empirical correlation matrix differs from the model-implied correlation matrix. The low value (0.8083) indicates a good fit.

HI95 (95% highest density interval) and HI99 (99% highest density interval) provide uncertainty intervals. The calculated values are less than the respective HI95 values for all tests. This suggests that the model provides a good fit to the data, as the fit statistics are within an acceptable range, considering the uncertainty in their estimates.

3.2.3. Measurement model parameter estimation

Dijkstra-Henseler's rho (ρ_A) measures the internal consistency reliability of the constructs in your model. It ranges from 0 to 1, where higher values indicate greater reliability. In our case, ρ_A for the Assessment construct (the only construct with latent variables) is 0.9267, suggesting a high internal consistency level among the items measuring by construct: the number of grade marks A, B, C, D, E, F/Fx, respectively.

Jöreskog's rho (Dillon-Goldstein's ρ, McDonald's ω), or composite reliability (ρ_c), measures internal consistency reliability of sum scores. A value closer to 1 indicates higher reliability. In our case, ρ_c is 0.9063, indicating good internal consistency among the items.

Cronbach's alpha (α) is a lower bound estimate of the reliability of sum scores. Like the previous measures, it ranges from 0 to 1, with higher values indicating greater reliability. Our α value is 0.9122, suggesting high internal consistency among the items.

The average variance extracted (AVE) equals the average indicator reliability. The

AVE is typically interpreted as a measure of unidimensionality. It ranges from 0 to 1, where higher values indicate that the indicators account for a larger proportion of the variance in the constructs. An AVE value of 0.6252 indicates that, on average, around 62.52% of the constructs' variance is captured by their respective indicators. The AVE value is greater than 0.5, indicating good convergent validity.

The diagonal AVE (table 3.2) is greater than other correlation coefficient values in the matrix, indicating excellent discriminant validity.

Table 3.2: Discriminant validity (Fornell-Larcker criterion).

Construct	**Information**	**Activities**	**Resources**	**Communication**	**Assessment**
Information	–				
Activities	0.0008	–			
Resources	0.0117	0.2429	–		
Communication	0.0003	0.6158	0.1145	–	
Assessment	0.2257	0.0000	0.0015	0.0000	0.6252

The table 3.3 presents factor loadings for different indicators across five constructs: Information, Resource, Activities, Communication, and Assessment. Factor loadings indicate the strength and direction of the relationship between an indicator and its corresponding construct.

After analyzing the table 3.3 in each construct were highlighted indicators which have the most strong (in bold) and weak (in italic) relationships. Educational level has a moderate negative loading (-0.3894), indicating an inverse relationship with the Information construct. According to the selected encoding for this indicator (table 2.1), the Moodle courses for bachelor students are better described in their introductions and syllabuses than for master students. In the Information construct, indicators like the

Table 3.3: Indicator loadings.

Construct	Indicator	Factor loading	Interpretation of relationship with the construct
Information	Form of education	0.1319	weak positive
	Semester	0.0385	very weak positive
	Status	-0.0065	very weak negative
	Educational level	-0.3894	moderate negative
	Number of teachers	0.9158	very strong positive
Resource	URL	0.7118	strong positive
	Book	-0.0277	very weak negative
	Label	0.2972	moderate positive
	Page	0.7864	strong positive
	Folder	0.0114	very weak positive
	File	0.0139	very weak positive
Activities	*H5P*	0.0028	very weak positive
	HotPot	0.0519	weak positive
	SCORM	0.7048	strong positive
	Survey	0.1590	moderate positive
	Database	-0.0204	very weak negative
	Choice	0.6384	strong positive
	Visiting	0.2762	moderate positive
	Wiki	0.0376	very weak positive
	Glossary	0.3940	moderate positive
	Assignments	0.5372	strong positive
	Feedback	0.0723	weak positive
	LTI External tool activity	-0.0004	very low
	Workshop	-0.0249	very weak negative
	Quiz	0.4063	moderate positive
	Lesson	0.3057	moderate positive
Comunication	Forum	0.4608	moderate positive
	Chat	0.9820	very strong positive
Assessment	**A**	0.5303	very strong positive
	B	0.7038	very strong positive
	C	0.7485	very strong positive
	D	0.7986	very strong positive
	E	0.8967	very strong positive
	F	0.9863	very strong positive

Number of teachers contribute significantly (0.9158), while others like Semester or Status have a relatively minor impact on the construct. In the Resource construct, URLs, Labels, and Pages play significant roles, while indicators like Books or Folders have a relatively minor effect on the construct. In the Activities construct, activities like SCORM, Choice, and Assignments play a significant role; others, like H5P or Workshops, have a relatively minor impact. Chat activities notably contribute significantly to the Communication construct, while Forums also play a substantial role in facilitating communication among learners and instructors.

In the Assessment construct, all indicators contribute significantly, with indicators like F (0.9863) playing a particularly prominent role in evaluating learner performance. To assess the indicator reliability, the squared standardized loadings were calculated.

1. Indicator F (lowest grade/fail) has an extremely high reliability of 0.9728 in measuring the Assessment construct. This suggests that a failing grade is a very reliable indicator of poor assessment performance.
2. Indicator E (low grade) also has a high reliability of 0.8041, meaning lower grades are reliable indicators of poorer assessment outcomes.
3. As the grades improve from D (0.6377) to C (0.5602) to B (0.4954), the indicator reliability decreases. This implies that higher grades become less reliable measures of the Assessment construct.
4. Indicator A (highest grade/pass) has the lowest reliability of 0.2812. A high/passing grade is not a very reliable indicator of the Assessment construct, likely because the construct encompasses a range of assessment outcomes, not just the highest level of performance.

In this context, the reliability values align with the expectation that lower grades are more reliable indicators of poor assessment performance, while higher grades are less reliable indicators of the overall Assessment construct, which includes a range of performance levels.

Indicator loadings represent the correlation between each indicator and its respective construct, while indicator weights (table 3.4) represent the contribution of each

Table 3.4: Indicator weights.

Construct	Indicator	Weights
Information	Form of education	0.1256
	Semester	-0.1519
	Status	0.0704
	Educational level	-0.4335
	Number of teachers	0.8964
Resource	URL	0.5784
	Book	-0.0281
	Label	0.1875
	Page	0.6743
	Folder	0.0366
	File	0.0740
Activities	H5P	-0.0131
	HotPot	0.0294
	SCORM	0.6686
	Survey	0.0974
	Database	-0.0216
	Choice	0.4750
	Visiting	0.1354
	Wiki	-0.0046
	Glossary	0.0251
	Assignments	0.1644
	Feedback	0.0416
	LTI External tool activity	-0.0480
	Workshop	-0.0125
	Quiz	0.1857
	Lesson	-0.0200
Comunication	Forum	0.1970
	Chat	0.9259
Assessment	A	0.1361
	B	0.1806
	C	0.1921
	D	0.2049
	E	0.2301
	F	0.2531

indicator to its respective construct. The weights and indicator loadings are consistent and positively correlated, which indicates robustness in the model.

As the Assessment construct is latent, its indicators loadings are placed in the conceptual model (figure 2.3). As all constructs except the Assessment are emergent, their weights are placed in the conceptual model (figure 2.3).

The cross-loadings table 3.5 shows the correlations between each indicator variable and the composite model constructs. To assess the discriminant validity of the measurement model, we should examine whether each indicator loads highest on its intended construct. Based on the table 3.5, all indicators load highest on their intended constructs.

Table 3.5: Cross loadings.

Indicator	**Information**	**Activities**	**Resources**	**Communication**	**Assessment**	**Interpretation**
Form of education	0.1319	-0.0611	-0.1165	-0.0499	0.0973	positively related to Information and Assessment
Semester	0.0385	0.0418	-0.0003	0.0071	0.0170	weakly positively related to all factors
Status	-0.0065	-0.0267	0.0253	-0.0368	-0.0091	weakly negatively related to Communication
Educational level	-0.3894	-0.0591	-0.0963	-0.0388	-0.1702	strongly negatively related to all factors, especially Information and Assessment
Number of teachers	0.9158	0.0215	0.0883	-0.0259	0.4376	strongly positively related to Information and Assessment, moderately to others
H5P	0.0004	0.0028	0.0116	-0.0042	-0.0007	weakly positively related to Resources

Continued on next page

Table 3.5 – continued from previous page

Indicator	Information	Activities	Resources	Communication	Assessment	Interpretation
HotPot	0.0323	0.0519	0.0952	-0.0042	-0.0154	weakly positively related to Activities and Resources
SCORM	-0.0153	0.7048	0.2474	0.6172	-0.0141	strongly related to Communication and Assessment, moderately to others
URL	0.1213	0.3409	0.7118	0.2396	0.0418	strongly related to Communication and Resources, moderately to others
Survey	-0.0337	0.1590	0.2310	0.0302	-0.0132	weakly positively related to Activities and Resources
Database	0.0261	-0.0204	-0.0278	-0.0042	0.2512	weakly positively related to Information and Assessment
Choice	0.0066	0.6384	0.2785	0.5240	-0.0148	strongly related to Communication and Assessment, moderately to others
Visiting	0.0177	0.2762	0.2379	0.1523	-0.0258	weakly positively related to Activities and Resources
Wiki	-0.0293	0.0376	0.0554	0.0073	-0.0200	weakly positively related to Activities and Resources
Glossary	0.0267	0.3940	0.2797	0.2550	0.0017	weakly positively related to Activities and Resources
Assignments	0.0140	0.5372	0.3588	0.3625	-0.0015	strongly related to Communication and Assessment, moderately to others
Feedback	-0.0056	0.0723	0.1452	-0.0119	-0.0154	weakly positively related to Activities and Resources
LTI External tool activity	0.0220	-0.0004	0.0045	-0.0042	-0.0134	weakly negatively related to Communication
Book	-0.0266	-0.0096	-0.0277	-0.0042	-0.0350	weakly negatively related to Communication
Label	-0.0159	0.1772	0.2972	0.0747	-0.0222	weakly positively related to Activities and Resources

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Table 3.5 – continued from previous page

Indicator	**Information**	**Activities**	**Resources**	**Communication**	**Assessment**	**Interpretation**
Workshop	-0.0105	-0.0249	-0.0300	-0.0080	0.0191	weakly positively related to Information
Page	0.0458	0.3904	0.7864	0.2757	0.0184	strongly related to Communication and Resources, moderately to others
Folder	0.1094	-0.0039	0.0114	-0.0170	0.0022	weakly positively related to Information
Quiz	0.1860	0.4063	0.3621	0.2116	0.1159	strongly related to Communication and Assessment, moderately to others
Lesson	-0.0036	0.3057	0.1031	0.2702	-0.0108	weakly positively related to Resources
File	0.0715	-0.0128	0.0139	0.0042	0.0645	weakly positively related to Information and Assessment
Forum	-0.0164	0.3385	0.2090	0.4608	-0.0093	strongly related to Communication and Assessment, moderately to others
Chat	-0.0141	0.7755	0.3209	0.9820	0.0067	strongly related to Communication and Assessment, moderately to others
A	0.2548	-0.0122	-0.0170	-0.0011	0.5303	strongly related to Information and Assessment, moderately to others
B	0.3368	-0.0101	-0.0048	0.0074	0.7038	strongly related to Information and Assessment, moderately to others
C	0.3586	-0.0145	-0.0076	-0.0165	0.7485	strongly related to Information and Assessment, moderately to others
D	0.3812	-0.0190	0.0079	-0.0081	0.7986	strongly related to Information and Assessment, moderately to others

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Table 3.5 – continued from previous page

Indicator	Information	Activities	Resources	Communication	Assessment	Interpretation
E	0.4230	0.0198	0.0732	0.0257	0.8967	strongly related to Information and Assessment, moderately to others
F	0.4643	0.0005	0.0910	0.0075	0.9863	strongly related to Information and Assessment, moderately to others

High positive cross-loading values (above 0.3) indicate that the indicator is strongly associated with the indicated construct. Low positive values (around 0.1 to 0.3) indicate a moderate association between the indicator and the construct. Values close to zero (around 0.0) suggest the indicator is weakly associated with that construct and may not be a good measure.

Removing indicators with consistently low loadings (close to zero or at least less than 0.1) is generally recommended across all constructs. Therefore, the following indicators can be removed: Semester, Status, H5P, HotPot, Wiki, Book, LTI External tool activity, Workshop, and File. This can mean that factors such as the Semester in which the course is touched and the course Status (normative or optional) are insufficient in this model. Excepting File, the other indicators are rare in the courses: 3 H5P activities contain only course ID 3314, 3 HotPot activities contain only course ID 182, 24 Wiki activities are in 4 courses of 985, 75 Book resources are in 24 courses of 985, 1 LTI External tool activity in only course ID 4248, 73 Workshop activities are in 8 courses of 985.

Table 3.6 shows the values for indicator multicollinearity (variance inflation factor

– VIF). Multicollinearity occurs when two or more predictors in a regression model are highly correlated with each other. For emergent constructs, multicollinearity may affect the indicator weights [71, p. 28].

Table 3.6: Indicator multicollinearity.

Construct	Indicator	Value
Information	Form of education	1.0089
	Semester	1.2950
	Status	1.0494
	Educational level	1.2756
	Number of teachers	1.0032
Resource	URL	1.0376
	Book	1.0035
	Label	1.0155
	Page	1.0498
	Folder	1.0322
	File	1.0403
Activities	H5P	1.0842
	HotPot	1.0194
	SCORM	1.3203
	Survey	1.0552
	Database	1.0042
	Choice	1.7799
	Visiting	1.1248
	Wiki	1.0414
	Glossary	1.2475
	Assignments	1.8277
	Feedback	1.1640
	LTI External tool activity	1.0946
	Workshop	1.0010
	Quiz	1.1380
	Lesson	1.2549
Communication	Forum	1.0883
	Chat	1.0883
Assessment	A	1.9784
	B	3.7548
	C	4.8197
	D	5.8080
	E	3.2687
	F	1.7761

VIF values can be interpreted as follows:

1. Values close to 1 (around 1.00 to 1.20) indicate a very weak or no multicollinearity issue. Most indicators in the model fall under this category, including those for Information (except Semester at 1.2950), Resources, Communication (both indicators have the same value of 1.0883), and most Activities (except Choice, Assignments, and Glossary).
2. Values between 1.2 and 5 indicate a moderate level of multicollinearity. In the given model, Semester and Educational level (Information), Choice (1.7799), Assignments (1.8277), Glossary (Activities), and Assessment indicator F (1.7761) fall into this range.
3. Values above 5 indicate a high degree of multicollinearity, which can be problematic for the model. Assessment indicator D (5.8080) fall into this range.

Generally, a value below 5 for an indicator is considered acceptable, while a value above 5 indicates potential multicollinearity issues. However, some researchers suggest more conservative thresholds, such as 3.3 or even lower. In the Assessment construct, the indicators C (4.8197), D (5.8080), and B (3.7548) have values above the conservative threshold of 3.3, suggesting potential multicollinearity concerns among these indicators. The indicators A (1.9784), E (3.2687), and F (1.7761) are within acceptable ranges.

While most constructs show no significant multicollinearity issues, the Assessment construct exhibits potential concerns, particularly among the indicators C, D, and B. The Activities construct also has two indicators (Choice and Assignments) with slightly elevated values, but not as severe as the Assessment construct. All concerned indicators have strong positive and very strong positive loadings on their intended construct, so they can't be removed to reduce redundancy and multicollinearity issues.

Specifically, the high VIF values for B, C, D, and E suggest that these grade indicators are highly correlated, meaning they measure or represent a similar underlying construct (in this case, student performance or achievement). For example, suppose a student scores a high grade (e.g., A or B) in one assessment component. They will likely score similarly high in other components, leading to a strong correlation among the grade indicators. Similarly, students who score low grades (e.g., D or F) in one component are likelier to score low grades in other components, contributing to multicollinearity.

Therefore, we decided to investigate multicollinearity among the different grades in depth. We divided the Assessment construct into up to 6 constructs with different grade combinations. The model with the lowest VIF values is shown in figure 3.1.

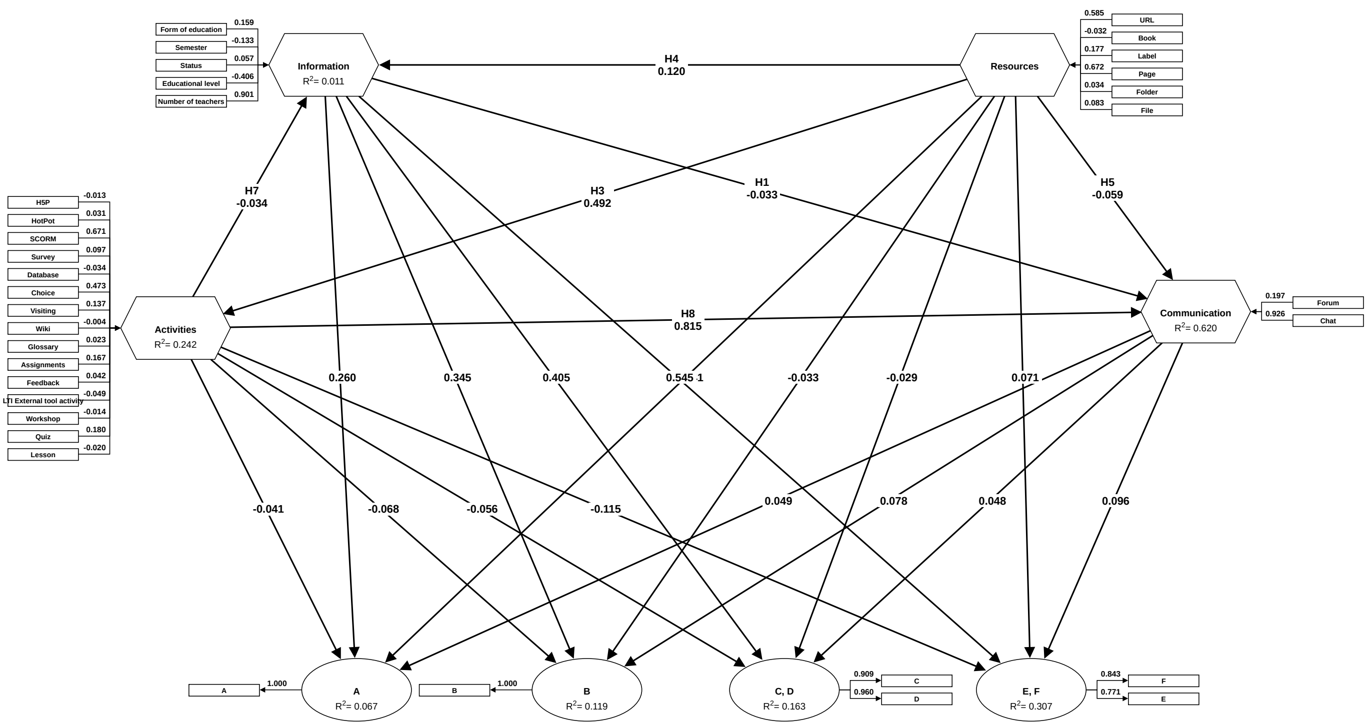

Figure 3.1: Updated conceptual model with Assessment construct split into 4.

The updated model contains four lateral constructs instead of one related to the following grades:

- Construct A contains indicator A only with VIF = 1.0000, which indicates no multicollinearity issue.
- Construct B contains indicator B only with VIF = 1.0000, which indicates no mul-

ticollinearity issue.

- Construct C, D contains indicators B and C with VIF = 4.1927, which indicates a moderate level of multicollinearity.
- Construct E, F contains indicators E and F with VIF = 1.7334, indicating a moderate multicollinearity level.

This probably indicates the real 4-grade scale used by teachers in KSPU, which corresponds to the shifted national scale: A is an excellent mark, B is a good mark, C and D can be satisfied marks, and E and F are failing marks, in fact. Moreover, the KSPU teachers are most uneven in their assessment when marks are C and D.

Moreover, it was impossible to build a model with a separate E grade: a review of digitized students' performance data shows that most E marks correspond to only one mark – 50 (the bottom level of the E mark according to the KSPU scale). In this regard, eliminating other scales used to assess students in KSPU besides the 4-grade national scale seems to be a good idea.

3.2.4. Structural equation modelling analysis

The coefficient of determination (R^2) represents the proportion of variance in the observed data that the model can explain. The adjusted coefficient of determination ($\overline{R}^2$) is a modification of the R^2 that takes the sample size into account and compensates for the independent variables added to the model (table 3.7).

Table 3.7: Coefficients of determination.

Construct	R^2	$\overline{R}^2$
Information	0.0125	0.0105
Activities	0.2429	0.2421
. In contrast,ine Communication	0.6200	0.6189
Assessment	0.2280	0.2249

The Communication construct has the highest R^2 and $\overline{R}^2$ values, suggesting a relatively good fit of the model for this construct. The Activities and Assessment constructs have moderate explanatory power, while the Information construct has a relatively low R^2 value, indicating that its indicators may not adequately explain the variance in this construct.

The regression coefficient consists of the coefficients of direct (path coefficient) and indirect effects.

Consider the influence of direct effects (direct path coefficient) in table 3.8. The path coefficients are standardized regression coefficients (beta values) shown in figure 2.3 on the arrows between constructs. A path coefficient quantifies the direct effect of an independent variable on a dependent variable. Path coefficients are interpreted as the increase in the dependent variable if the independent variable were increased by one standard deviation and all the other independent variables in the equation remained constant [71].

Table 3.8: Direct effects.

Independent variable	**Dependent variable**			
	Information	**Activities**	**Comunication**	**Assessment**
Information			-0.0334	0.4785
Activities	-0.0321		0.8152	-0.0755
Resources	0.1239	0.4928	-0.0598	-0.0005
Communication				0.0715

Interpretation of table 3.8 results:

- **Information on Assessment**: There seems to be a positive and relatively strong effect (β_{10} = 0.4785) of Information on Assessment. This suggests that the better-described course leads to increased Assessment.
- **Information on Communication**: There's a weak negative effect (β_1 = -0.0334) of Information on Communication. The course that was better described might

lead to a slight decrease in communication. However, the magnitude of this effect is very small.

- **Activities on Assessment**: Activities have a negative effect (β_9 = -0.0755) on Assessment. An increase in Activities might lead to a slight decrease in Assessment scores. But again, the effect is weak.
- **Activities on Communication**: Activities have a strong positive effect (β_8 = 0.8152) on Communication. This means that more Activities are associated with increased Communication.
- **Resources on Information**: Resources have a positive but weak effect (β_4 = 0.1239) on Information. An increase in Resources might lead to a slightly better-described course.
- **Resources on Activities**: There's a moderate positive effect (β_3 = 0.4928) of Resources on Activities. More Resources are associated with an increase in Activities.
- **Resources on Communication**: The effect of Resources on Communication is negative (β_5 = -0.0598) but weak. An increase in Resources might lead to a slight decrease in Communication.
- **Communication on Assessment**: The effect of Communication on Assessment is positive but weak (β_2 = 0.0715). An increase in Communication might lead to a slight increase in Assessment.
- **Activities on Information**: There's a weak negative effect (β_7 = -0.0321) of Activities on Information. An increase in Activities might lead to a slightly worse-describe course. However, the magnitude of this effect is very small.
- **Resources on Assessment**: The effect of Resources on Assessment is negative (β_6 = -0.0005) but very weak. Therefore, it can be neglected.

In addition to direct effects, indirect effects were also calculated. An indirect effect occurs when an independent variable influences a dependent variable through one or more intervening variables.

The indirect effects are related to all possible paths between the constructs. Therefore, to calculate indirect effects, we should multiply the related betas (table 3.9):

- Information through Communication on Assessment: $\beta_1 \cdot \beta_2$
- Resources through Activities on Information: $\beta_3 \cdot \beta_7$
- Resources through Activities on Communication: $\beta_3 \cdot \beta_8$
- Resources through Activities on Assessment: $\beta_3 \cdot \beta_9$
- Resources through Activities through Information on Communication: $\beta_3 \cdot \beta_7 \cdot \beta_1$
- Resources through Activities through Information on Assessment: $\beta_3 \cdot \beta_7 \cdot \beta_{10}$
- Resources through Activities through Communication on Assessment: $\beta_3 \cdot \beta_8 \cdot \beta_2$
- Resources through Activities through Information through Communication on Assessment: $\beta_3 \cdot \beta_7 \cdot \beta_1 \cdot \beta_2$
- Resources through Information on Assessment: $\beta_4 \cdot \beta_{10}$
- Resources through Information on Communication: $\beta_4 \cdot \beta_1$
- Resources through Information through Communication on Assessment: $\beta_4 \cdot \beta_1 \cdot \beta_2$
- Resources through Communication on Assessment: $\beta_5 \cdot \beta_2$
- Activities through Information on Communication: $\beta_7 \cdot \beta_1$
- Activities through Information on Assessment: $\beta_7 \cdot \beta_{10}$
- Activities through Information through Communication on Assessment: $\beta_7 \cdot \beta_1 \cdot \beta_2$
- Activities through Communication on Assessment: $\beta_8 \cdot \beta_2$

All indirect effects (except the effect of Resources on Communication, which equals 0.3981) show a weak positive or negative effect. This suggests a very small indirect influence. But there's a strong positive indirect effect ($\beta_3 \cdot \beta_7 \cdot \beta_1 = 0.3981$) of Resources on Communication. This suggests a substantial indirect influence, possibly through other

Table 3.9: Indirect effects.

Independent variable	Dependent variable			
	Information	**Activities**	**Comunication**	**Assessment**
Information				-0.0024
Activities			0.0011	0.0430
Resources	-0.0158		0.3981	0.0387
Communication				

variables, that increases Communication as Resources increase.

The sum of direct and indirect effects is the total effects (table 3.10):

- Information on Communication: β_1
- Communication on Assessment: β_2
- Resources on Activities: β_3
- Resources on Information: $\beta_4 + \beta_3 \cdot \beta_7$
- Resources on Communication: $\beta_5 + \beta_3 \cdot \beta_8 + \beta_3 \cdot \beta_7 \cdot \beta_1 + \beta_4 \cdot \beta_1$
- Resources on Assessment: $\beta_6 + \beta_3 \cdot \beta_9 + \beta_3 \cdot \beta_7 \cdot \beta_{10} + \beta_3 \cdot \beta_8 \cdot \beta_2 + \beta_3 \cdot \beta_7 \cdot \beta_1 \cdot \beta_2 + \beta_4 \cdot \beta_{10} + \beta_4 \cdot \beta_1 \cdot \beta_2 + \beta_5 \cdot \beta_2$
- Activities on Information: β_7
- Activities on Communication: $\beta_8 + \beta_7 \cdot \beta_1$
- Activities on Assessment: $\beta_9 + \beta_7 \cdot \beta_{10} + \beta_7 \cdot \beta_1 \cdot \beta_2 + \beta_8 \cdot \beta_2$
- Information on Assessment: $\beta_{10} + \beta_1 \cdot \beta_2$

Table 3.10: Total effects.

Independent variable	Dependent variable			
	Information	**Activities**	**Comunication**	**Assessment**
Information			-0.0334	0.4761
Activities	-0.0321		0.8163	-0.0325
Resources	0.1081	0.4928	0.3383	0.0383
Communication				0.0715

Comparing direct effects (table 3.8) and total effects (table 3.10), we can conclude that the strength of the effects has almost not changed, except for the influence of Resources on Communication, since there is a strong indirect effect.

The overview of effects related to hypotheses is presented in table 3.11.

Table 3.11: Effect overview.

Hypothesys	**Effects**			**Cohen's f^2**	**Interpretation**
	Direct	**Indirect**	**Total**		
H1	-0.0334		-0.0334	0.0029	unsubstantial effect
H2	0.0715		0.0715	0.0025	unsubstantial effect
H3	0.4928		0.4928	0.3208	moderate effect
H4	0.1239	-0.0158	0.1081	0.0118	unsubstantial effect
H5	-0.0598	0.3981	0.3383	0.0071	unsubstantial effect
H6	-0.0005	0.0387	0.0383	0.0000	unsubstantial effect
H7	-0.0321		-0.0321	0.0008	unsubstantial effect
H8	0.8152	0.0011	0.8163	1.3232	strong effect
H9	-0.0755	0.0430	-0.0325	0.0024	unsubstantial effect
H10	0.4785	-0.0024	0.4761	0.2920	moderate effect

Table 3.11 contains Cohen's f^2, which indicates how substantial a direct effect is, and its interpretation according to Cohen [31, p. 477-478].

After analysing the table 3.11, we can select the strongest effects:

- H8 (Activities on Communication) has the strongest overall effect (0.8163) with a strong effect size (1.3232), indicating a substantial positive influence of Activities on Communication.
- H3 (Resources on Activities) has a strong positive total effect (0.4928) with a moderate effect size (0.3208), suggesting a significant impact of Resources on Activities.
- H10 (Information on Assessment) has a moderate positive total effect (0.4761) with a moderate effect size (0.2920), indicating a notable influence of Information on Assessment.

H5 (Resources on Communication) has a strong positive total effect (0.3383) with an unsubstantial effect size (0.0071) due to the prevailing indirect effects.

The inter-construct correlation matrix contains the estimated correlations between constructs (table 3.12).

Table 3.12: Inter-construct correlations.

Construct	Information	Activities	Resources	Communication	Assessment
Information	1.0000				
Activities	0.0290	1.0000			
Resources	0.1081	0.4928	1.0000		
Communication	-0.0163	0.7848	0.3383	1.0000	
Assessment	0.4751	-0.0057	0.0383	0.0043	1.0000

Results presented in table 3.12 agree with the results in table 3.11. Activities and Communication (H8) have a strong positive correlation (0.7848). This indicates that these two constructs tend to increase together in the model. Resources (H3) show a moderate positive correlation with Activities (0.4928). Information and Assessment (H10) have a moderate positive correlation (0.4751). There's a positive association between Information and Assessment.

The final decision on the particular hypothesis's acceptance or rejection should be based on the total effects inference (table 3.13).

H1 (Information on Communication): the original coefficient (total effect) is -0.0334, and the bootstrap results show a mean value of -0.0348 with a standard error of 0.0191. The t-value is -1.7512, resulting in a p-value of 0.0802. The percentile bootstrap quantiles show that the coefficient lies between -0.1033 and -0.0037 at the 95% confidence level. With a p-value above the typical threshold of 0.05, we fail to reject the null hypothesis, suggesting that there is no significant effect of Information on Communication.

H2 (Communication on Assessment): the original coefficient is 0.0715, and the boot-

Table 3.13: Total effects inference.

Hypothesis	Total effect	Standard bootstrap results					Percentile bootstrap quantiles			
		Mean value	Standard error	t-value	p-value (2-sided)	p-value (1-sided)	0.5%	2.5%	97.5%	99.5%
H1	-0.0334	-0.0348	0.0191	-1.7512	0.0802	0.0401	-0.1033	-0.0768	-0.0037	0.0131
H2	0.0715	0.0807	0.0502	1.4248	0.1545	0.0773	-0.0981	0.0011	0.1727	0.3452
H3	0.4928	0.5135	0.0683	7.2155	0.0000	0.0000	0.2948	0.3755	0.6419	0.6763
H4	0.1081	0.1087	0.0490	2.2050	0.0277	0.0138	-0.0047	0.0217	0.2063	0.2418
H5	0.3383	0.3511	0.0651	5.1989	0.0000	0.0000	0.1573	0.2121	0.4758	0.5122
H6	0.0383	0.0333	0.0301	1.2731	0.2033	0.1016	-0.0433	-0.0245	0.0967	0.1150
H7	-0.0321	-0.0310	0.0384	-0.8360	0.4033	0.2017	-0.1268	-0.1013	0.0527	0.0902
H8	0.8163	0.8257	0.1268	6.4386	0.0000	0.0000	0.1241	0.5440	1.0220	1.0329
H9	-0.0325	-0.0314	0.0327	-0.9911	0.3219	0.1609	-0.1097	-0.0920	0.0323	0.0765
H10	0.4761	0.4720	0.0780	6.1057	0.0000	0.0000	0.2599	0.3545	0.5860	0.6221

strap results show a mean value of 0.0807 with a standard error of 0.0502. The t-value is 1.4248, resulting in a p-value of 0.1545. The percentile bootstrap quantiles show that the coefficient lies between -0.0981 and 0.3452 at the 95% confidence level. With a p-value above 0.05, we fail to reject the null hypothesis, suggesting no significant indirect effect of Communication on Assessment.

H3 (Resources on Activities): the original coefficient is 0.4928, and the bootstrap results show a mean value of 0.5135 with a standard error of 0.0683. The t-value is 7.2155, resulting in a very low p-value (close to zero). The percentile bootstrap quantiles indicate a significant positive effect, with a coefficient between 0.2948 and 0.6763 at the 95% confidence level. Thus, strong evidence supports the hypothesis that Resources influence Activities positively.

H4 (Resources on Information): the original coefficient is 0.1081, and the bootstrap results show a mean value of 0.1087 with a standard error of 0.0490. The t-value is 2.2050, resulting in a p-value of 0.0277. The percentile bootstrap quantiles indicate a significant positive effect, with a coefficient between -0.0047 and 0.2418 at the 95% confidence level. Thus, evidence supports the hypothesis that Resources influence Information positively.

H5 (Resources on Communication): the original coefficient is 0.3383, and the bootstrap results show a mean value of 0.3511 with a standard error of 0.0651. The t-value is 5.1989, resulting in a very low p-value (close to zero). The percentile bootstrap quantiles indicate a significant positive effect, with the coefficient between 0.1573 and 0.5122 at the 95% confidence level. Thus, strong evidence supports the hypothesis that Resources influence Communication positively.

H6 (Resources on Assessment): the original coefficient is 0.0383, and the bootstrap results show a mean value of 0.0333 with a standard error of 0.0301. The t-value is 1.2731, resulting in a p-value of 0.2033. The percentile bootstrap quantiles show that the coefficient lies between -0.0433 and 0.1150 at the 95% confidence level. With a p-value above 0.05, we fail to reject the null hypothesis, suggesting no significant indirect effect of Resources on Assessment.

H7 (Activities on Information): the original coefficient is -0.0321, and the bootstrap results show a mean value of -0.0310 with a standard error of 0.0384. The t-value is -0.8360, resulting in a p-value of 0.4033. The percentile bootstrap quantiles show that the coefficient lies between -0.1268 and 0.0902 at the 95% confidence level. With a p-value above 0.05, we fail to reject the null hypothesis, suggesting no significant indirect effect of Activities on Information.

H8 (Activities on Communication): the original coefficient is 0.8163, and the bootstrap results show a mean value of 0.8257 with a standard error of 0.1268. The t-value is 6.4386, resulting in a very low p-value (close to zero). The percentile bootstrap quantiles indicate a significant positive effect, with the coefficient between 0.1241 and 1.0329 at the 95% confidence level. Thus, substantial evidence supports the hypothesis that Activities influence Communication positively.

H9 (Activities on Assessment): the original coefficient is -0.0325, and the bootstrap results show a mean value of -0.0314 with a standard error of 0.0327. The t-value is -0.9911, resulting in a p-value of 0.3219. The percentile bootstrap quantiles show that the coefficient lies between -0.1097 and 0.0765 at the 95% confidence level. With a p-value above 0.05, we fail to reject the null hypothesis, suggesting no significant indirect effect of Activities on Assessment.

H10 (Information on Assessment): the original coefficient is 0.4761, and the bootstrap results show a mean value of 0.4720 with a standard error of 0.0780. The t-value is 6.1057, resulting in a very low p-value (close to zero). The percentile bootstrap quantiles indicate a significant positive effect, with a coefficient between 0.2599 and 0.5860 at the 95% confidence level. Thus, there is strong evidence to support the hypothesis that Information influences Assessment positively.

Based on the total effects inference (table 3.13) we accepted the hypothesis H3, H4, H5, H8, and H10. Using total effects interpretation (table 3.11), we can conclude the unsubstantial effects in H4 and H5, moderate in H3 and H10, and strong in H8. Therefore, we can conclude the following:

1. There is *insufficient evidence* to conclude whether there is a significant relationship between the Information and Communication constructs in the Moodle course.
2. There is *insufficient evidence* to conclude whether there is a significant relationship between the Communication and Assessment constructs in the Moodle course.
3. There is a **moderate positive relationship** between the Resources and Activities constructs in the Moodle course.
4. There is an **insignificant positive relationship** between the Resources and Information constructs in the Moodle course.
5. There is **an insignificant indirect positive relationship** between the Resources

construct and Communication construct in the Moodle course.

6. There is *insufficient evidence* to conclude whether there is a significant relationship between the Resources construct of the Moodle course and the external Assessment constructs.
7. There is *insufficient evidence* to conclude whether there is a significant relationship between the Activities construct and Information construct in the Moodle course.
8. There is a **strong positive relationship** between the Activities construct and Communication construct in the Moodle course.
9. There is *insufficient evidence* to conclude whether there is a significant relationship between the Activities construct of the Moodle course and the external Assessment construct.
10. There is a **moderate positive relationship** between the Information construct of the Moodle course and the external Assessment construct.

Therefore, the *answers to the research questions* are:

1. **There is a significant relationship between the resources and activities and between the activities and communication in the Moodle course.**
2. **There is a significant relationship between the information about the Moodle course and the student's performance, and there is no evidence of a relationship between the number of components used in the Moodle course and student performance.**

3.3. Discussion

The results of this study provide insights into the interconnectedness of various components within the Moodle learning environment and their potential impact on student learning outcomes. Several key findings emerged from the analysis.

Firstly, a strong positive relationship was identified between the Activities and

Communication constructs (H8). This finding suggests that increased utilization of interactive activities within a Moodle course is associated with higher levels of communication and engagement among learners and instructors. Activities such as SCORM packages, choices, assignments, and quizzes foster a more dynamic and communicative learning experience, potentially enhancing collaboration, discussion, and feedback.

Secondly, a moderate positive relationship was observed between the Resources and Activities construct (H3). This result indicates that the availability and variety of resources (e.g., URLs, pages, labels) within a Moodle course are linked to the inclusion of diverse learning activities. Courses with a richer resource base tend to incorporate a broader range of interactive activities, potentially contributing to a more engaging and multimodal learning experience.

Thirdly, a moderate positive relationship was found between the Information and external Assessment constructs (H10). This suggests that the quality and comprehensiveness of course information, such as the course description, syllabus, and introduction, are associated with improved student performance as measured by assessment scores. Well-designed and informative course materials may aid in setting clear expectations, providing guidance, and supporting students in achieving better learning outcomes.

However, the study did not find evidence of a significant relationship between the Communication and Assessment constructs (H2) nor between the Activities and Assessment constructs (H9). These results suggest that while communication and interactive activities are essential components of an effective learning environment, their direct impact on student performance, as measured by assessment scores, may be more complex and influenced by other factors.

Additionally, the Resources construct showed an insignificant positive relationship with the Information construct (H4) and an insignificant indirect positive relationship with the Communication construct (H5). While the availability of resources may contribute to better course information and indirectly facilitate communication, these effects appear to be relatively weak in the context of this study.

It is important to note that the interpretation of these findings should be contextualized within the specific setting of this study and the limitations inherent in the data and methodological approaches employed.

3.4. Conclusion

This study explored the interconnectedness of various components within the Moodle learning environment and their potential impact on student learning outcomes. The findings provide valuable insights into the relationships among information, resources, activities, communication, and assessment within the context of Moodle courses.

The results revealed a strong positive relationship between the Activities and Communication constructs, suggesting that incorporating interactive learning activities fosters increased communication and engagement among learners and instructors. Additionally, a moderate positive relationship was found between the Resources and Activities construct, indicating that the availability of diverse resources is linked to including a wider range of interactive activities.

Notably, the study identified a moderate positive relationship between the Information and Assessment constructs, highlighting the importance of providing comprehensive and well-designed course information to support better student performance. However, the direct relationships between communication, activities, and assessment were not significant, suggesting that other factors or more complex dynamics may influence the impact of these components on student performance.

The research findings presented have important practical implications for enhancing the use of Moodle LMS and improving student learning outcomes in pedagogical universities:

1. Instructors should incorporate more interactive activities (e.g., SCORM, assignments, quizzes) in their Moodle courses, as these activities are strongly linked to increased communication and engagement among students and instructors. This can contribute to a more effective learning experience.
2. Providing a diverse range of resources (URLs, pages, labels, etc.) within Moodle courses is associated with including more diverse learning activities. This emphasizes the importance of curating a rich and varied collection of resources to support various learning activities.
3. Well-designed and informative course materials (course descriptions, syllabi, introductions) are associated with better student assessment performance. Instructors should prioritize creating comprehensive, clear course information to facilitate better learning outcomes.
4. While communication and interactive activities are crucial, their direct impact on assessment performance appears to be mediated by other factors. Instructors should explore additional strategies to translate increased engagement and communication into improved assessment outcomes effectively.
5. The availability of resources alone may not guarantee better course information or facilitated communication. To maximise their effectiveness, instructors should consider how resources are organized, presented, and integrated with other course components.
6. The research findings suggest that using Moodle tools does not automatically ensure the implementation of adaptive learning. Instructors and course designers must intentionally leverage Moodle's adaptive features, such as personalized

learning paths, content adaptation based on student performance or learning styles, and learning analytics, to inform instructional decisions and interventions.

Additionally, the insights gained from this research can inform the continuous improvement of Moodle course design and implementation strategies.

The main results of the third chapter are presented in scientific work [53].

CONCLUSION

Answers to research questions

In this research, we attempted to answer the four research questions.

What are the key thematic clusters and trends in the literature on adaptive learning in higher education based on keyword analysis, and how do these clusters relate?

With the help of a bibliometric review, the main directions of research in adaptive learning were determined. Based on the cluster analysis, there are five main thematic clusters identified in the literature on adaptive learning in higher education:

1. General concepts of adaptive learning in e-learning systems
2. Educational technology
3. Adaptive learning systems and education computing
4. Learning and education research
5. Personalized learning

These clusters are closely interconnected and not isolated entities. Advancements or findings in one cluster can have implications and contribute to developments in other clusters, suggesting a multidimensional and dynamic nature of research in adaptive learning.

Specifically, the analysis highlights the importance of AI technologies in developing adaptive learning systems (cluster 3) and the significance of personalized education and catering to individual learning styles (cluster 5). Additionally, various approaches within adaptive learning systems, such as their development, implementation, and effectiveness evaluation, are emphasized (clusters 3 and 4).

How interconnected are the different Moodle resources and activities used by teachers of pedagogical universities?

To answer this question, we employ a quantitative SEM-PLS approach to investigate the relationships between various constructs derived from Moodle LMS and student assessment outcomes. Data from Kryvyi Rih State Pedagogical University (KSPU) were used for the empirical analysis.

The conceptual model was developed based on the social constructionist pedagogy underlying Moodle's development and the university regulations regarding Moodle's course structure and assessment. The model comprised five constructs: Information, Resources, Activities, Communication, and Assessment. The Information, Resources, Activities, and Communication are emergent constructs formed using indicators directly observed from Moodle course data, while the Assessment construct was a latent construct reflecting student performance data.

According to the modelling results, the different Moodle resources and activities used by teachers of pedagogical universities exhibit varying degrees of interconnectedness:

1. There is a strong positive relationship between the Activities and Communication constructs. This suggests that increased utilization of interactive activities within Moodle courses is associated with higher levels of communication and engagement among learners and instructors.
2. There is a moderate positive relationship between the Resources and Activities construct. This indicates that the availability and variety of resources within a Moodle course are linked to the inclusion of diverse learning activities.
3. There is an insignificant positive relationship between the Resources and the Information construct, suggesting a relatively weak association between resources

and the quality of course information.

4. There is an insignificant indirect positive relationship between the Resources and Communication construct, implying a relatively weak indirect link between resources and communication facilitated through other factors.

The modelling results reveal a strong interconnectedness between activities and communication and a moderate interconnectedness between resources and activities within the Moodle environment used by teachers of pedagogical universities. However, based on the findings of this study, the interconnectedness between resources and course information and the indirect relationship between resources and communication appear to be relatively weak.

How does using the different Moodle tools influence student learning outcomes?

The key findings from the modelling results regarding how different Moodle tools influence student learning outcomes are:

1. A strong positive relationship exists between the Activities construct (interactive learning activities like SCORM, choices, assignments, and quizzes) and the Communication construct. This suggests that using more interactive activities in Moodle courses increases communication and engagement among students and instructors, enhancing the learning experience.
2. A moderate positive relationship exists between the Resources construct (URLs, pages, labels, etc.) and the Activities construct. Having various resources in a Moodle course is linked to incorporating more diverse learning activities.
3. A moderate positive relationship exists between the Information construct (course description, syllabus, introduction) and the Assessment construct (student grades). Well-designed and informative course materials are associated with better student performance on assessments.

4. However, the study did not find evidence of a significant direct relationship between Communication or Activities and the Assessment construct. While these are essential components, their impact on assessment performance appears more complex and influenced by other factors.
5. The availability of resources showed a weak positive relationship between providing better course information and indirectly facilitating communication, but these effects were relatively small.

Using interactive activities, providing diverse resources, and ensuring comprehensive course information seem to contribute positively to student engagement, communication, and potentially better learning outcomes based on assessments. However, this study did not establish the direct impact of communication activities on assessment scores.

Does the use of Moodle tools guarantee the implementation of adaptive learning for students of pedagogical universities?

Based on the research findings presented, there is insufficient evidence to conclude that the mere use of Moodle tools guarantees the implementation of adaptive learning for students of pedagogical universities.

While Moodle provides tools and features that could potentially support adaptive learning, such as personalized learning paths, adaptive content delivery, and learning analytics, the mere presence and use of these tools do not necessarily guarantee the implementation of adaptive learning. Effective adaptive learning requires careful instructional design, integration of appropriate pedagogical strategies, and the strategic use of Moodle's adaptive capabilities in alignment with specific learning objectives and student needs.

The research indicates that factors like interactive activities, diverse resources, and comprehensive course information contribute to Moodle's engaging and effective learning environment. However, to truly implement adaptive learning, instructors and course designers must intentionally leverage Moodle's adaptive features, such as personalized learning paths, content adaptation based on student performance or learning styles, and learning analytics to inform instructional decisions and interventions.

While using Moodle tools can facilitate elements of an engaging and practical learning experience, implementing adaptive learning requires a more deliberate and strategic approach beyond using Moodle's tools and features.

Limitations

1. The primary limitations of the research stem from the exclusive use of the Scopus database and, specifically, the social sciences section of this database rather than its entire range. This is particularly noteworthy given the potential relevance of this topic to other fields, such as engineering. We conducted a similar search in the Web of Science database to determine whether this first limitation is critical. This search yielded 290 documents, and their distribution by years (figure A.1) mirrors the distribution of documents from the Scopus database (figure 1.1). Although not all documents listed in Web of Science are included in Scopus and vice versa, they exhibit a similar distribution of keywords by clusters.
2. The VOSViewer tool has some restrictions: a clustering algorithm was applied with the default settings, and the low limit for keyword occurrence was set at 10. The number of clusters can be decreased or increased depending on the clustering settings. Additionally, the third cluster can be combined with the fifth one because the fifth cluster only has one keyword (personalized learning).
3. Additionally, this research used sources like technical reports and PhD theses that Scopus does not index. Before 2022, most of these sources from the National

Repository of Academic Texts (Ukraine) were not indexed by web search engines.

4. Using only one term, such as "adaptive learning", for a cluster-based literature review in a specialized field like adaptive learning in higher education can effectively capture the majority of relevant studies due to a consensus around this term that is widely accepted and used across the literature. Also, using a single keyword like "adaptive learning" can help to reduce the number of false positives in the search results that might be retrieved when using multiple terms.
5. The study was conducted within the specific context of Kryvyi Rih State Pedagogical University in Ukraine. The findings may not be directly generalizable to other higher education institutions or different educational contexts.
6. The data was collected from Moodle LMS courses and student assessment data at Kryvyi Rih State Pedagogical University. The results could be influenced by factors specific to how Moodle is implemented and utilized at this institution.
7. The Moodle data and student assessment data were collected from the specific period – 6 months after the COVID-19 pandemic began and 1 month before the full-scale Russian invasion of Ukraine started.
8. The study focused on the relationships between Moodle constructs (Information, Resources, Activities, Communication) and the Assessment construct based on student grades. However, other factors or variables could influence student learning outcomes, which were not accounted for in this research.
9. The study relied on quantitative data analysis using structural equation modelling. While this approach provides valuable insights into the relationships between constructs, it may not capture the nuances and complexities of the learning experience that could be better understood through qualitative or mixed-methods approaches.
10. The Assessment construct was based solely on student grades, which may not

fully represent the breadth and depth of student learning outcomes. Other measures of learning, such as skill development, knowledge retention, or application of knowledge, could provide a more comprehensive understanding of the impact of Moodle tools on student learning.

11. The study did not directly investigate Moodle courses' specific pedagogical strategies or instructional design approaches. These factors could potentially influence the effectiveness of Moodle tools and the implementation of adaptive learning.

Future work

Building on research results, several areas of future research can be explored to advance our understanding of adaptive learning and its applications in education:

1. *AI-driven adaptive learning*: investigate the role of artificial intelligence in developing adaptive learning systems and explore the use of advanced AI algorithms and approaches to enhance the adaptivity and personalization of learning experiences.
2. *Evaluation and effectiveness*: examine the implementation and effectiveness of adaptive learning systems in educational settings and conduct empirical studies to assess the impact of adaptive learning on student performance, engagement, and satisfaction. This can also involve conducting a longitudinal study to investigate the long-term effects of using Moodle tools on student learning outcomes, along with incorporating additional variables or factors that may influence student learning outcomes, such as student characteristics (e.g., learning styles, prior knowledge, motivation), instructional design approaches, pedagogical strategies, or the specific subject matter being taught.
3. *Investigating alternative measures of student learning outcomes* beyond grades or assessment scores like skill development, knowledge retention, application of knowl-

edge in real-world scenarios, or other relevant indicators of learning effectiveness.

4. *Adaptive learning environments*: explore the design and development of adaptive learning environments that cater to individual learners' needs and preferences and investigate how adaptive systems can be integrated into existing educational platforms to create personalized learning experiences.
5. *Gamification and adaptive learning*: investigate the potential of gamification techniques in adaptive learning systems and explore how gamified elements can enhance student motivation, engagement, and learning outcomes.
6. *Learning styles and personalization*: study the role of learning styles in adaptive learning systems and investigate how learning styles can be effectively integrated into adaptive learning platforms to cater to diverse learner preferences.
7. *Analytics and adaptive learning*: explore learning analytics in adaptive learning systems and investigate how data-driven insights can personalize learning pathways and support educators in making informed decisions.
8. *Replication in different educational contexts and institutions to generalize research findings and application in different educational settings*: investigate the implementation of adaptive learning and analytics in various educational settings, including K-12 schools, higher education institutions, corporate training, online learning platforms, across different subject domains or educational levels, and potentially in different countries or cultural settings.
9. *Employing mixed-methods research designs that combine quantitative data analysis with qualitative approaches*, such as interviews, observations, or focus groups to provide a more comprehensive understanding of the learning experience, including students' and instructors' perspectives, challenges faced, and contextual factors influencing the use of Moodle tools; conducting intervention studies or

experimental designs to directly examine the impact of implementing adaptive learning strategies or features within Moodle LMS on student learning outcomes, engagement, and overall learning experience.

10. *Ethical and privacy considerations*: examine the ethical and privacy implications of using adaptive learning systems, especially when leveraging AI and data-driven approaches and address concerns related to data security, bias, and transparency.
11. *Exploring the specific pedagogical strategies and instructional design approaches employed in Moodle courses*, and how these factors interact with using Moodle tools to support adaptive learning and personalized learning experiences.

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APPENDIX A

Additional tables

The additional tables contain the data from the ADANCO report [51].

The empirical correlation matrix contains the Pearson correlations between the indicators (see https://ssemerikov.github.io/Fadieieva/#diagnostics for details).

The model-implied correlation matrix contains the Pearson correlations that one would obtain if the model were true. Since ADANCO determines the model fit for the estimated and the saturated model, there are two implied correlation matrices (see https://ssemerikov.github.io/Fadieieva/#diagnostics for details).

Construct scores are given in the related tables (see Scores section of Fadieieva and Semerikov [51]).

Descriptive statistics are given in the table A.1.

Table A.1: Descriptive statistics.

Indicator	Min	Max	Mean	Variance	Skewness	Kurtosis
Form of education	1	3	1.380710659898	0.368123478189	1.353784912705	0.741641349749
Semester	1	8	3.547208121827	5.508185795056	0.428200297023	-1.246815584926
Status	1	2	1.131979695431	0.114677479262	2.177937535012	2.748989495539
Educational level	1	2	1.179695431472	0.147554785193	1.671087506454	0.794141801265
Number of teachers	1	9	1.220304568528	0.629262102266	6.000257378182	43.544021098460
H5P	0	3	0.003045685279	0.009137055838	31.384709652947	984.999999999990
HotPot	0	3	0.003045685279	0.009137055838	31.384709652945	984.999999999986
SCORM	0	15	0.049746192893	0.699758573728	17.546453305425	310.447247759291
URL	0	83	10.777664974619	152.892590070572	2.425267146080	7.272182578563
Survey	0	1	0.002030456853	0.002028393380	22.158450988097	489.991855438687
Database	0	9	0.009137055838	0.082233502538	31.384709652951	984.999999999941
Choice	0	1	0.004060913706	0.004048532871	15.620402161659	242.489324692026
Visiting	0	3	0.074111675127	0.093079113532	4.670230863140	24.765687300823
Wiki	0	11	0.024365482234	0.204690272791	20.818659296760	455.997318453488
Glossary	0	5	0.030456852792	0.064112087821	13.186418456526	218.393173881489
Assignments	0	142	9.998984771574	171.769307911354	4.720778757469	38.875039143155
Feedback	0	2	0.013197969543	0.015069539020	10.134587634970	114.112133910836
LTI External tool activity	0	1	0.001015228426	0.001015228426	31.384709652950	985.000000000024
Book	0	20	0.076142131980	0.682204613924	17.977014806108	382.084184332232
Label	0	117	1.935025380711	35.343334984111	10.573404480864	162.241344909966

Continued on next page

Table A.1 – continued from previous page

Indicator	Min	Max	Mean	Variance	Skewness	Kurtosis
Workshop	0	25	0.074111675127	1.172347406215	18.292719175775	369.966788471463
Page	0	53	2.256852791878	31.871967727292	5.379104620374	32.854250293837
Folder	0	22	0.298477157360	2.979926540382	8.790684680163	87.823442093184
Quiz	0	93	2.613197969543	37.343118319508	6.609059498685	70.679247651135
Lesson	0	17	0.088324873096	0.794020056952	12.952355927452	192.377066221204
File	0	54	2.650761421320	34.955144236722	3.538406574724	16.235060542331
Forum	0	13	1.177664974619	0.544622590896	9.161219524317	122.436141892000
Chat	0	1	0.008121827411	0.008064050184	10.977252356329	118.741164476201
A	0	75	5.318781725888	46.014128595601	3.713774056665	21.942235858980
B	0	67	4.260913705584	34.601570302505	4.458474834662	32.380219072669
C	0	137	6.233502538071	115.555177252280	5.600139009417	44.389933454580
D	0	110	4.938071065990	66.403681234781	5.427451570063	46.986291184072
E	0	176	7.262944162437	141.966359209277	5.765780778986	57.072140053105
F	0	92	3.197969543147	48.041052783624	5.696253939604	49.262256880339

Original and standardized indicator scores are given in https://ssemerikov.github.io/Fadieieva/#data.

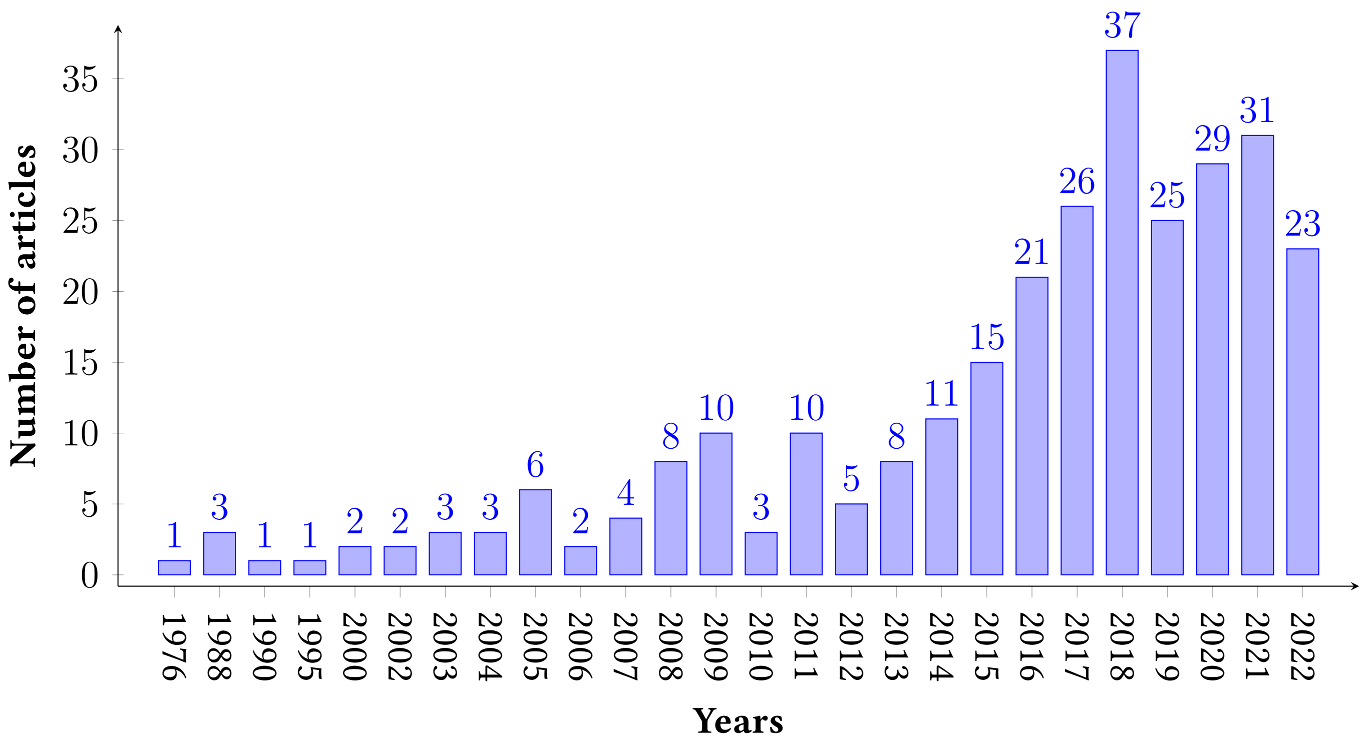

Figure A.1: Distribution of articles from Web of Science database by years.

APPENDIX B

List of L. O. Fadieieva's scientific works on dissertation topic and information on approbation of dissertation results

B.1. List of L. O. Fadieieva's scientific works on dissertation topic

Scientific works in which the main scientific results of the dissertation are published

1. Fadieieva, L.O., 2021. Enhancing adaptive learning with Moodle's machine learning. *Educational Dimension*, 5, p.1–7. URL https://doi.org/10.31812/ed.625. **(article in the journal included in the list of specialized scientific publications of Ukraine)**
2. Fadieieva, L.O., 2023. Adaptive learning: a cluster-based literature review (2011-2022). *Educational Technology Quarterly*, 2023(3), p.319–366. URL https://doi.org/10.55056/etq.613. **(article in the journal included in the list of specialized scientific publications of Ukraine)**
3. Fadieieva, L.O., 2023. Adaptive learning concept selection: a bibliometric review of scholarly literature from 2011 to 2019. *Educational Dimension*, 9, p.136–148. URL https://doi.org/10.31812/ed.643. **(article in the journal included in the list of specialized scientific publications of Ukraine)**

Scientific works certifying the scientific results of the dissertation

4. Fadieieva, L.O., 2023. Bibliometric Analysis of Adaptive Learning Literature from 2011-2019: Identifying Primary Concepts and Keyword Clusters. In: G. Antoniou, V. Ermolayev, V. Kobets, V. Liubchenko, H.C. Mayr, A. Spivakovsky, V. Yakovyna and G. Zholtkevych, eds. *Information and Communication Technologies in Education, Research, and Industrial Applications*. Cham: Springer Nature Switzerland,

Communications in Computer and Information Science, pp.215–226. URL https://doi.org/10.1007/978-3-031-48325-7_16. **(article in the foreign scientific publication indexed by Scopus)**

Scientific works that additionally reflect the scientific results of the dissertation

5. Fadieieva, L. and Semerikov, S., 2024. KSPU Moodle activities and marks 2020-2022. URL https://doi.org/10.5281/zenodo.10938019. **(dataset)**

B.2. Information on approbation of L. O. Fadieieva's dissertation results

Conference title	Venue and date of the event	Participation form
18th International Conference on Information and Communication Technologies in Education, Research, and Industrial Applications (ICTERI 2023)	Ivano-Frankivsk, Ukraine, September 18–22, 2023	in-person
4th International Conference on History, Theory and Methodology of Learning (ICHTML 2023)	Kryvyi Rih, Ukraine, October 12-13, 2023	in-person
VII International Scientific and Practical Conference "Information Technology for Education, Science, and Technics" (ITEST-2024)	Cherkasy, Ukraine, May 23-24, 2024	in-person