ISSN 1453 – 7303 **"HIDRAULICA" (No. 3/2025)**
Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics*

Pedagogical Valences of Computer-Assisted Instruction in the Professional Training of Soil Remediation Specialists

MA stud. **Ioana-Elisabeta CIORUȚA[1,2],** PhD Eng. IT exp. **Bogdan V. CIORUȚA[1,3,4,*]**, Assoc. Prof. PhD Eng. habil. **Mirela-Ana COMAN[5,6]**, Eng. IT exp. **Alexandru L. POP[1,3]**

[1] Technical University of Cluj-Napoca - North University Centre of Baia Mare, Faculty of Letters, Department of Specialty with Psychopedagogical Profile, 76 Victoriei Str., 430083, Baia Mare, Romania

[2] "Little Prince" Extended Program Kindergarten, 8B Cuza Vodă Str., 430034, Baia Mare, Romania

[3] Technical University of Cluj-Napoca - North University Centre of Baia Mare, Office of Informatics, 62A Victor Babeș Str., 430083, Baia Mare, Romania

[4] Technical University of Cluj-Napoca - North University Centre of Baia Mare, Faculty of Science, 76 Victoriei Str., 430072, Baia Mare, România

[5] Technical University of Cluj-Napoca - North University Centre of Baia Mare, Faculty of Engineering - Department of Mineral Resources, Materials and Environmental Engineering, 62A Victor Babeș Str., 430083, Baia Mare, Romania

[6] University of Agricultural Sciences and Veterinary Medicine from Cluj-Napoca, 3-5 Calea Mănăștur, 4000372, Cluj-Napoca, Romania

* bogdan.cioruta@staff.utcluj.ro

Abstract: *The accelerated degradation of soil resources represents one of the most pressing global challenges of the 21st century, requiring a rapid and well-founded response from society. In this context, the professional training of specialists capable of efficiently and innovatively addressing complex problems related to soil pollution becomes a strategic priority. As such, the present research aims to analyze and argue the implications and valences of Computer-Assisted Instruction (CAI) as a modern and indispensable pedagogical solution in the training of these specialists. The motivation for this scientific approach stems from the need to adapt educational methods to the rapid evolution of remediation technologies and the increasing complexity of pollution scenarios. By integrating CAI, the radical transformation of the learning process aims to shift from a passive model (based on the transmission of information) to an active, interactive one tailored to individual needs. Digital technologies (computer simulations, virtual reality, and e-learning platforms) offer the opportunity to reproduce pollution scenarios in controlled environments, to practice remedial interventions without risks, and to assimilate cutting-edge knowledge. At the same time, CAI is not only a content delivery tool, but a skills development platform essential to prepare a new generation of specialists capable of acting effectively in the face of ecological emergencies. This article demonstrates that the digitalization of the educational process in the field is a requirement for efficiency and sustainability, contributing decisively to the protection of the environment and natural resources.*

Keywords: *Digitalization, vocational training, assisted training, soil protection, decontamination technologies.*

1. Introduction

Soil degradation is not only an ecological problem (via agricultural development and ecological sustainability), but also a socio-economic and public health one [1-3]. Its effective approach requires a specialized workforce, capable of using the latest technologies and remediation methodologies [4-6]. In this context, in human interaction with the environment [7], the purpose of this study is to argue for the essential role of Computer-Assisted Instruction (CAI) as a modern and efficient tool in the professional training of soil remediation specialists, but also as an integrated part of Environmental Information Systems (EISs) and Environmental Informatics (EI) [8,9]. The intended purpose is not only to describe a teaching method, but to demonstrate that CAI can build a superior educational framework, directly responding to the needs of the ecological emergencies.
Classical training programs are often based on static materials and on content that can quickly become outdated, given the rapid pace of innovations in the field of bioremediation,

phytoextraction, or stabilization techniques. They have difficulties in realistically simulating the complexity of a polluted site, with types of contaminants, geological layers, and potential risks.
In light of the above, Table 1 illustrates the evolution of methods and tools used in the training of soil remediation specialists, reflecting technological progress and paradigm shifts in environmental education over several decades. The latter can be grouped into three distinct stages, reflecting the evolution of the relevance and complexity of soil remediation specialist training.

Table 1: A perspective on the dynamics of professional training of specialists in soil decontamination, by reporting to the reference interval 1950-2030

Stage	Decade	Technologies and training tools available to specialists	Observations
Stage 1 ***Fundamental training***	1950-1960	Textbooks, classical university courses, lessons in the amphitheater	Training based on theoretical knowledge. Emphasis on chemistry, geology, and basic principles of hydrology. Absence of a discipline dedicated to soil decontamination.
	1960-1970	Lessons, small-scale practical demonstrations & first written case studies	The emergence of the first courses focused on pollution. The beginning of the application of knowledge in case studies, but limited to descriptions and theoretical analyses.
	1970-1980	The use of early computers for calculation and mathematical modeling	Computers are used to run simple pollutant dispersion models. The training tools remain theoretical and mathematical, accessible only in specialized research centers.
Stage 2. ***Training through transition to technology***	1980-1990	Specialized software programs (primitive GIS), access to rudimentary databases	The first software dedicated to mapping and spatial analysis (GIS) appears. Students begin to work with digital maps, but the interface is complex and limited.
	1990-2000	Educational CD-ROMs, environmental databases, and Internet access	The spread of personal computers and the Internet has revolutionized access to information. CD-ROM courses offer interactive multimedia content. Learning becomes more accessible.
	2000-2010	E-learning platforms (Moodle, Blackboard), online courses, webinars	The emergence of the first large-scale e-learning platforms. Vocational training becomes more flexible. Online communities of practice are developed, and knowledge exchange is facilitated.
Stage 3. ***Digitalized & integrated training***	2010-2020	3D Simulations, Virtual Reality (VR), Mobile Applications, Big Data	An explosion of immersive technologies. Learners can "explore" polluted sites in VR. Using Big Data from IoT sensors for real-time analysis. Mobile micro-learning is becoming popular.
	2020-2030	Adaptive learning with AI, blockchain for certification, Augmented Reality (AR)	AI personalizes the learning process for each learner. Blockchain ensures the integrity of digital diplomas. Training becomes interconnected, personalized, and transparent.

Each stage marks a qualitative leap, from a purely theoretical approach to a fully integrated, technology-assisted one, as follows:

- Stage 1 - **Fundamental Training (1950-1980)** - this period was marked by a theoretical and rudimentary approach. Training was focused on basic disciplines, such as chemistry, geology, and hydrology, without a dedicated specialization in soil remediation. Training tools were classic, based on textbooks and lectures in the amphitheater. The direct relevance of the training was limited because the available technology was insufficient to model complex processes in the field.

- Stage 2 - **Training through the transition to technology (1980-2010)** - this stage represented a transition from theory to practice, facilitated by the emergence and spread of personal computers and the Internet. Training became more accessible and interactive. The first GIS programs and databases allowed specialists to start working with real data and visualize environmental problems in a spatial context. The emergence of e-learning platforms and online courses democratized access to information, allowing for more flexible learning. However, interaction remained predominantly on the screen, with simulations and practical applications still limited.
- Stage 3 - **Digitalized and Integrated Training (2010-2030)** - the current and future period is defined by a fully integrated and personalized approach, in which technology is no longer a simple tool, but an intrinsic part of the learning process. Technologies such as virtual reality (VR) and augmented reality (AR) allow for immersive simulations and assisted interventions in the field, while artificial intelligence (AI) personalizes the learning trajectory for each specialist. The use of blockchain for certifications ensures transparent and trusted validation of skills. The relevance of the training is maximum, as it prepares specialists not only with knowledge, but also with practical skills and adaptability.

CAI overcomes these barriers by using advanced technologies, such as:

- **Virtual simulations** - allow learners to virtually visit and intervene on a contaminated site, from the initial risk assessment to the planning and implementation of a remediation plan.
- **Interactive e-learning platforms** - provide access to an updated database of case studies, best practices, and current legislation, ensuring a continuous and relevant learning process.
- **Augmented Reality (AR)** - can be used in the field to overlay geological data or contamination maps on the real image of the soil, helping specialists visualize the complexity of the situation.

By integrating these tools, active and personalized learning is facilitated, transforming the learner from a simple receiver of information into an active participant in solving problems. Ultimately, the use of CAI not only modernizes the educational process but also directly contributes to the formation of a new generation of specialists, better prepared, more agile, and more capable of contributing to global environmental protection efforts.

2. Literature Review - a Synthesis of Research on CAI in the Training of Specialists with Responsibilities in Soil Decontamination

Recent scientific literature highlights a growing convergence between digital technologies and environmental education, if we consider the mobile applications dedicated to soil protection [10,11]. Most of the considered reference publications demonstrate that the effective use of CAI radically transforms the process of knowledge acquisition and skills development among specialists [12], especially in relation to the integrated development of an environmental virtual field laboratory [13-16], as shown in Fig. 1.

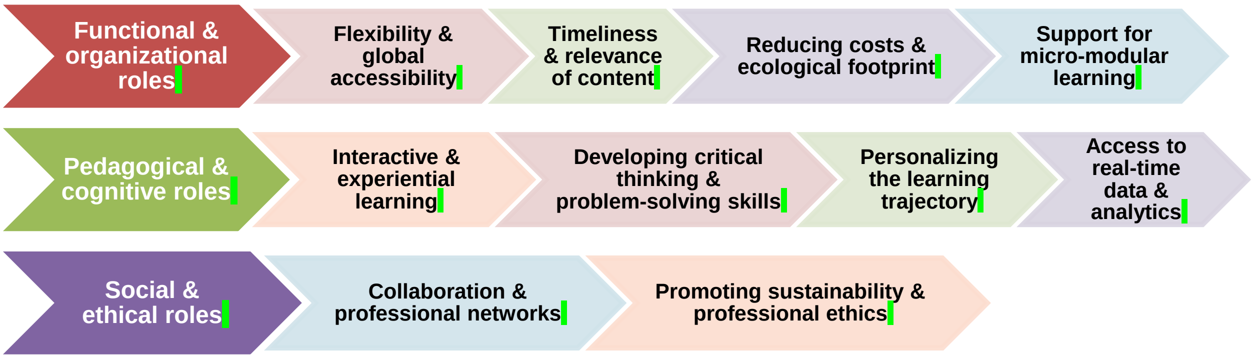

Fig. 1. Categories of benefits associated with the integration of CAI in the professional training of soil remediation specialists

The elements presented in Fig. 1, according to the structure that we have built on three categories that reflect the fundamental roles of CAI in professional training, demonstrate to us that the studies considered do not just theorize, but provide concrete evidence of the major benefits of CAI, which go beyond the simple transmission of information. In this regard, we can mention and highlight the following aspects, respectively:

- **Flexibility and global accessibility** - research shows that e-learning formats eliminate geographical and temporal barriers, allowing specialists and students to access high-quality courses remotely; this aspect is crucial for a field with dispersed expertise, facilitating the exchange of good practices globally and access to specialization courses offered by top universities, regardless of the geographical location of the learner.
- **Interactive and experiential learning** - studies on serious games and digital simulations in education emphasize that they significantly increase the information retention rate and the ability to apply knowledge; Unlike a theoretical course, a soil remediation simulation allows students to test different technologies (e.g., *bioremediation*, *phytoextraction*, *stabilization*) and observe in real time the effects of their decisions, more easily understanding the complexity of degradation processes and chemical reactions.
- **Timeliness and relevance of content** - one of the biggest advantages (often discussed in the specialized literature) is the ability of e-learning platforms to be updated quickly. Thus, in a field where legislative regulations and technologies are constantly evolving, this speed of update is essential. Learners have immediate access to the latest research, case studies, and methodologies, ensuring that their training is always in line with the latest standards in the field.
- **Reduction of costs and ecological footprint** - many of the articles in the field emphasize that, in addition to the pedagogical benefits, CAI also contributes to a substantial reduction in training costs (e.g., *costs related to transportation*, *accommodation*, *printed materials*), making specialized education more accessible. This aspect is relevant for the field of soil remediation, where the optimization of financial resources is a fundamental principle.
- **Developing critical thinking and problem-solving skills** - CAI platforms, through the use of interactive case studies and problem-based scenarios, encourage learners (future specialists) to analyze complex situations, evaluate multiple remedial options, and adequately justify the decisions made. This approach, supported by research in the field of digital pedagogy, is vital for training specialists who not only know the theories but also know how to apply them in unpredictable situations.
- **Collaboration and professional networks** - the literature indicates an increase in productivity and innovation among online communities of practice. Discussion forums, webinars, and virtual group projects allow specialists to collaborate from different locations, exchange experiences, and build a strong professional network, which is essential for addressing environmental problems (including those associated with soil resource pollution) that do not respect geographical boundaries.
- **Adaptation (appropriate personalization) of the learning trajectory** - modern CAI systems, often based on artificial intelligence algorithms, can monitor the progress of each learner and adapt the didactic content according to the pace and learning style. This ensures a deepening of difficult concepts and an acceleration of learning in familiar areas, thus optimizing training time and guaranteeing better assimilation of knowledge.
- **Support for micro-modular learning** - an emerging trend in professional training, documented by recent studies, is the shift to micro-learning, which involves breaking down complex information into short, easy-to-digest modules. CAI perfectly facilitates this approach, allowing learners to go through specific segments about a particular technology or contaminant when they need it, directly on their mobile. This flexibility is crucial for specialists in the field.
- **Unconditional access to databases and real-time analysis** - CAI platforms can be integrated with geospatial databases and environmental monitoring systems, giving learners access to real-time information on soil conditions, pollution maps, and the progress of remediation projects. This access to big data enables evidence-based learning and a deeper understanding of the impact of decontamination decisions.

- **Promoting sustainability and professional ethics** - through interactive scenarios and case studies focused on long-term impact, CAI can configure, shape, and reinforce a culture of responsibility and professional ethics among future specialists. Simulations can illustrate not only the technical success of a remediation project, but also the social, economic, and ecological consequences of the decisions made, preparing professionals aware of their role in society.

3. Materials and Methods

The methodological approach of this study is based on a systematic review of the specialized literature. The main research material consisted of scientific articles, case studies, research reports, and normative documents, all extracted from internationally recognized academic databases. To ensure the quality and relevance of the information, specific and relevant search terms for high-quality publications were used. These were strategically combined to obtain precise results. Among the search terms used (see Fig. 2) are: *e-learning for environmental education*, *computer-assisted instruction in soil remediation* [17-19], *digital tools for professional training in environmental science*, *virtual reality in soil pollution*, *online learning for environmental specialists*, *blended learning in environmental engineering*, *gamification for environmental training*, *micro-learning in professional development* [20-22], *blockchain for professional certification*, *AI in adaptive learning for environmental sustainability*, etc.

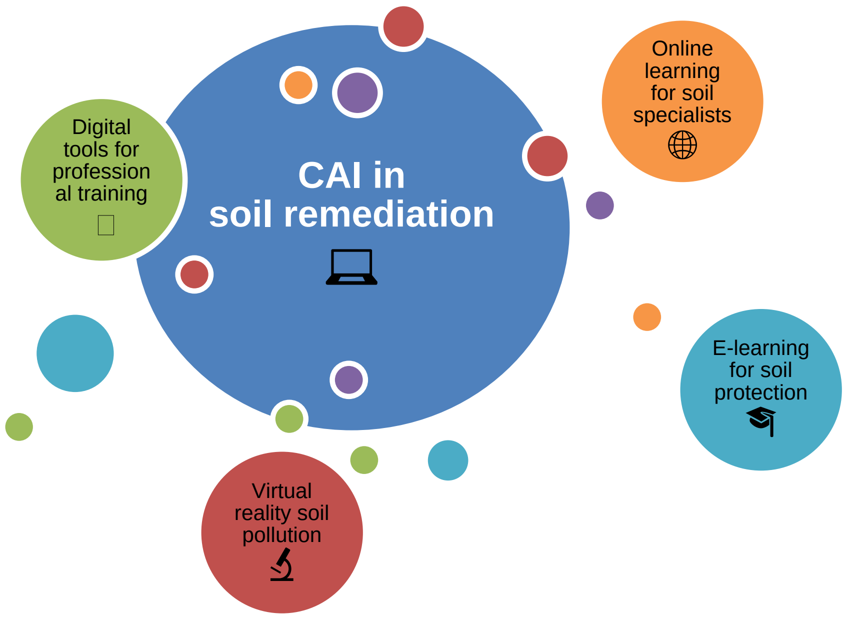

Fig. 2. Search terms used to index relevant publications associated with the integration of CAI in the professional training of soil remediation specialists

The search process was carried out on academic reference platforms, such as Web of Science, Google Scholar, and on the websites of prestigious organizations, such as the Environmental Protection Agency (EPA) and the European Environment Agency (EEA). The method involved the following stages, namely: identification of relevant literature - an extensive search was carried out using the above terms, with filtering by year (last 5-10 years), to ensure the timeliness of the information, data synthesis - the selected articles were critically analyzed to identify the role, impact and valences of CAI in the context of training specialists in soil remediation, correlation of concepts - a direct correlation was established between the benefits of CAI (e.g., *flexibility*, *interactivity*) and the specific needs of the soil remediation field (e.g., *simulation of complex scenarios*, *access to real-time data*). Based on the synthesized data, a set of concrete proposals and recommendations for good practice was developed, aimed at maximizing the efficiency of vocational training.

4. Results on the Synergy between Technology and Human Expertise in Soil Remediation

The analysis of the role, impact, and purpose of CAI in the professional training of soil remediation specialists reveals a complex pedagogical architecture, which, according to our results, summarized in Table 2, demonstrates that CAI is a catalyst in the development of essential skills that contribute to the formation of a specialist better equipped to face the challenges in the field.

Table 2: A perspective on CAI, as an efficient and innovative pedagogical architecture, in relation to the professional training of soil remediation specialists

Stage & assoc. level	The role of CAI in training	Impact on future specialists	Pedagogical purpose (finality)
Stage 1. ***Substantiation & assimilation*** (introductory level)	*E-learning platforms with online courses*	*Access to updated content, tailored to needs* The platforms not only offer courses, but also integrate self-assessment modules, expert discussion forums, and global case study databases, ensuring that future specialists are up to date with the latest regulations.	Ensuring a high level of theoretical knowledge and continuous learning
	Digitalized tests and assessments	*Self-assessment of progress and identification of learning gaps* Digitalized assessment systems provide fast and personalized feedback, allowing a future specialist to be evaluated based on performance in simulation scenarios.	Personalize your learning journey and get quick feedback
Stage 2. ***Practice & experimentation*** (intermediate level)	*Databases and interactive GIS*	*Ability to analyze and visualize complex data* CAI platforms can integrate data on soil types, specific contaminants, and pollution history, which allows for a more informed intervention plan.	Developing data analysis and strategic planning skills
	Simulations and VR	*Improving decision-making in complex and dynamic pollution scenarios* Students (future specialists) can navigate through the 3D structure of the soil, visualize the spread of pollutants, and simulate the impact of various intervention methods, which contributes to refining professional judgment.	Developing practical skills without the risks and costs of real operations
	Interactive case studies and gamification	*Motivating and increasing engagement in learning* Students solve complex case studies as if they were on a mission, applying knowledge in a fun and stimulating way, which strengthens not only knowledge but also team spirit.	Increasing the efficiency of the learning process through active involvement and intrinsic motivation
Stage 3. ***Connection & continuous development*** (advanced level)	*Online collaboration through forums and webinars*	*Connecting with experts in the field* Interactive webinars and forums transform learners into active members of a community, thus creating a synergy that stimulates innovation and collective solving of complex problems.	Creating a community that leads to the exchange of experiences and the solving of common problems
	Micro-learning on mobile devices	*Adaptive, continuous, and rapid learning* Specialists can access short learning modules directly on their mobile devices to quickly familiarize themselves with a new sampling technique or work protocol.	Ensuring real-time skills and professional adaptability to field needs

The use of CAI tools aims to create more agile, informed, and adaptable specialists, able to use technology not only as a tool, but also as a way of thinking and solving problems. Ultimately, the impact extends beyond the individual, contributing to a more effective and sustainable approach to pollution problems at the societal level.

5. Perspectives and Proposals - a Strategic Vision for the Future of Soil Remediation Specialist Training

For CAI to become an essential component and not just a complement to traditional soil remediation training, it is crucial to outline a clear vision and formulate concrete proposals based on current technological and pedagogical trends. Beyond the simple use of e-learning platforms, a deeper integration of technology is needed to create a complete educational ecosystem.
To maximize the impact of CAI in the training of soil remediation specialists, we believe it is crucial to formulate concrete proposals, each supported by a solid pedagogical justification. In these circumstances, Table 3 presents a synthesis of the strategic vision, associating each proposal with the educational reasoning that underlies it.
The proposals in Table 3 are ordered chronologically and pedagogically, starting from an introductory and fundamental level (familiarization with the basic notions), towards an advanced level (practical application and innovation). This order reflects a logical training path, from theory to practice and from the individual to the community, which is based on:

- **recognized digital certifications** - to motivate students and provide them with a concrete goal, it is essential to establish a clear system of recognition of skills at the beginning; this way, the learner knows from the very beginning that their efforts will be validated.
- **development of integrated educational platforms** - an immediate next step is to create the learning environment, in the form of a unified platform that serves as the foundation, on which all other stages will be built.
- **integration of AI and adaptive learning** - as learners start using the previously developed platform, the AI can start analyzing their progress; as such, personalization of learning becomes effective only after there is a sufficient volume of data.
- **creation of virtual remediation laboratories** - once learners have assimilated the theoretical concepts, it is time to apply them. Virtual laboratories provide a safe environment to experiment, understand, and learn the principles of how remediation methods work.
- **IoT integration in simulations** - integrating real-time data through IoT sensors makes exercises more realistic and allows learners to learn to manage dynamic information.
- **AR for field interventions** - represents a transition from the virtual to the physical environment. AR assists the specialist directly in the field, combining digital data with reality, a crucial stage before taking on full responsibilities.
- **mirror decontamination projects** - at this level, the learner applies all the knowledge in a real project, while benefiting from the support and data of an existing project. It is an advanced stage of practical learning, which closely imitates professional work.
- **virtual mentoring systems** - as they become more advanced, learners need guidance from experts. Virtual mentoring systems become a valuable tool to deepen knowledge and navigate the complexities of the job market.
- **modular courses based on crisis scenarios** - represent the culmination of training, preparing specialists for emergencies; previously acquired skills are tested under pressure, in a controlled environment.
- **use of blockchain for certification of skills** - once training is completed, diplomas and certifications must be secure and verifiable. The use of blockchain, at the end of the educational path, ensures the integrity and professional value of all efforts made.

Table 3: A perspective on CAI, as a significant strategic vision, in relation to the professional training of specialists in soil decontamination

Stage & assoc. level	Proposal (strategic vision)	Pedagogical justification (CAI involvement)	Pedagogical purpose (finality)
Stage 1. ***Substantiation & assimilation*** (introductory level)	*Recognized digital certifications* (🏆)	*Increasing credibility and motivation* Official recognition of skills acquired online transforms e-learning from a simple optional activity into a valid professional path.	Increasing the professional value of specialists & facilitating their employment on the labor market
	Development of integrated educational platforms (🌐)	*Holistic & contextual training* A unified platform allows learners to connect theoretical information with practical applications, creating a learning environment that reflects reality.	Training specialists with an integrated vision of decontamination processes
	Integrating AI & adaptive learning (🤖)	*Personalizing learning* AI allows the content and pace of study to be adjusted according to the individual needs of each learner, maximizing the efficiency of the process.	Optimizing training time & ensuring deep assimilation of knowledge
Stage 2. ***Application & experimentation*** (intermediate level)	*Creating virtual decontamination laboratories* (🧪)	*Learning by doing* Virtual labs provide a safe environment to experiment, test hypotheses, and observe the consequences of actions.	Developing critical thinking & practical skills without risks or material costs
	Integrating IoT into simulations (📡)	*Data-driven learning* Connecting simulations to real data, transmitted via IoT, transforms the case study into a dynamic experience.	Developing data analysis skills & the ability to make informed decisions
	AR for field interventions (📱)	*Real-time cognitive assistance* AR provides visual and informational support directly on the ground, overlaying virtual data over the real environment.	Optimizing decision-making in the field & reducing professional errors
Stage 3. ***Practice, collaboration & specialization*** (advanced level)	*Decontamination projects in the mirror* (🤝)	*Connecting theory with practice* Participation in projects that reflect real field work bridges the gap between knowledge and application in authentic situations.	Training specialists with practical experience relevant to the challenges in the field
	Virtual mentoring systems (👦🤝👦)	*Collaborative & guided learning* Virtual mentoring allows junior specialists to benefit from the experience of seniors in a flexible format.	Facilitating the transfer of tacit knowledge & building solid professional networks.
	Modular courses based on various crisis scenarios (🚨)	*Developing emergency response skills* Crisis simulations force learners to quickly apply knowledge, make decisions under pressure, and manage resources.	Training specialists to deal with unpredictable & dangerous situations, with rapid reaction.
Stage 4. ***Consolidation & validation*** (post-training level)	*Using blockchain for skills certification* (⛓)	*Ensuring transparency & trust* An immutable, verifiable, blockchain-based certification gives a high level of reliability to degrees earned online.	Strengthening employers' trust in digital training & combating fraud.

Consequently, we can say that the future of professional training for soil remediation specialists is digital. Therefore, the previous proposals do not only aim at modernizing the tools, but at a fundamental transformation of the way specialists are trained, transforming them into agile, innovative, and well-connected professionals to the global community.

6. Conclusions and Good Practice Recommendations

The best practice recommendations for integrating CAI into the training of soil remediation specialists, explained in Table 4, can be ordered in a logical and pedagogical sequence, from strategic planning to implementation and continuous evaluation. This process can be structured in three distinct stages, which build on each other, respectively:

- Stage 1 - **Strategic planning and substantiation** - is critical and precedes the launch of any digital training program. Without a solid foundation, subsequent efforts risk being ineffective or unrecognized.
  - **creating a legislative and regulatory framework** - the first step is to obtain legitimacy, without the official recognition of digital diplomas and certifications, training efforts would have no value on the labor market. This legal framework ensures that professionals are validated and that employers have confidence in their skills.
  - **partnerships with industry** - to guarantee relevance, collaboration with companies in the field is essential. Thus, the programs align with real market requirements and ensure access to case studies and practical data.
  - **investment in digital infrastructure and OER** - a CAI program cannot function without a robust technological base. Investments in e-learning platforms and open databases are essential to support large-scale training and to democratize access to education.
  - **creation of training of trainers programs** - even with the best tools, success depends on the quality of teaching. Preparing educators to effectively use new technologies ensures quality content delivery and maximizes the potential of CAI tools.
  - **standardization of formats and interfaces** - to avoid technological barriers, platforms and materials must be standardized and compatible. This makes the learning process accessible and uniform for all learners.
- Stage 2 - **Implementation and Execution** - focuses on applying modern pedagogical principles in the actual conduct of training, transforming theory into practice.
  - **blended learning** - the learning process must combine the flexibility of online courses with practical sessions in the laboratory or in the field. This balanced approach ensures a complete transfer of skills from theory to practice.
  - **gamification of the learning process** - to maintain commitment and increase motivation, gamification elements must be integrated from the beginning. This turns the study into a more enjoyable and efficient experience, stimulating the active involvement of learners.
  - **continuous and project-based assessment** - throughout the training, a constant assessment, focused on practical projects, ensures that specialists not only accumulate knowledge, but can also effectively apply it in solving complex problems in the field.
- Stage 3 - **Monitoring, evaluation, and continuous development** - after implementation, the focus shifts to maintaining the program relevance and encouraging long-term learning.
  - **continuous monitoring and evaluation of CAI programs** - once the program is underway, it is essential to collect feedback and analyze performance to identify strengths and make necessary adjustments.
  - **promoting a culture of lifelong learning** - most importantly, CAI must cultivate a mindset of continuous learning among specialists. Digital platforms are also the ideal tool to support this approach in the long term, ensuring that specialists always remain relevant and competitive in the labor market.

Table 4: A perspective on good practice recommendations associated with the integration of CAI in the continuous and long-term professional training of soil remediation specialists

Stage & assoc. level	Good practice recommendation	Pedagogical justification (CAI involvement)	Pedagogical purpose (finality)
Stage 1. ***Strategic planning & substantiation*** (introductory level)	*Creating a coherent legislative and regulatory framework*	Official validation of digital training provides credibility and professional security. This legitimate framework ensures that online training efforts are recognized by employers and authorities.	Increasing trust in digital training and recognition on the labor market of skills obtained online
	Partnerships with industry	Collaboration with companies in the field ensures the relevance of educational content and its alignment with the real demands of the labor market.	Aligning vocational training with the concrete needs of the labor market
	Creating training of trainers programs	Training educators to effectively use new technologies ensures the quality delivery of digital content. A good trainer can maximize the potential of CAI tools.	Increasing the quality of teaching and the efficiency of training programs
	Investments in digital infrastr. & OER	Investments in platforms and open resources contribute to the democratization of education and stimulate innovation. Access to a common knowledge base improves the quality of training.	Ensuring a solid technological base and the necessary resources to support CAI at scale
	Standardization of formats and interfaces	National and international standardization of content and interfaces eliminates technological barriers and ensures a uniform learning experience.	Democratizing access to training and optimizing the user experience
Stage 2. ***Implementation & execution*** (intermediate level)	*Blended learning*	Combining online courses with practical sessions (laboratory/field) provides a balanced approach that connects theory with practice.	Ensuring complete skills and professional adaptability in the field
	Gamification of the learning process	Integrating game elements increases student motivation and engagement, transforming the learning process into a memorable and more engaging experience.	Increasing information retention rate and training efficiency
	Continuous and project-based evaluation	A continuous assessment system, based on virtual projects, allows for real-time progress monitoring and provides personalized feedback, emphasizing the application of knowledge in solving real dynamic problems.	Training specialists with demonstrated practical skills, not just theoretical knowledge
Stage 3. ***Monitoring, evaluation & continuous development*** (advanced level)	*Continuous monitoring and evaluation of programs*	Collecting feedback and analyzing performance data allows programs to be adjusted according to the needs of learners and the evolution of the field.	Continuous improvement of the quality of CAI programs, based on concrete evidence
	Promoting lifelong learning	CAI is the ideal tool to facilitate continuous learning, providing flexible and constant access to new information.	Ensuring that specialists remain relevant and competitive in a constantly evolving field

The integration of CAI into the training of soil remediation specialists is no longer a simple option, but a fundamental necessity imposed by the complexity of environmental problems and the rapid pace of technological innovation. The analysis highlighted that CAI transforms the educational process from a static and passive one, based on the unidirectional transmission of information, into a dynamic, interactive, and adaptive one.

CAI acts as a catalyst for the modernization of environmental education, enabling the transition from a didactic model focused on memorization to a pedagogical one focused on the development of skills. By using simulations, interactive databases, and virtual (immersive) case studies, CAI drastically reduces the gap between theoretical knowledge and its practical application; this is, moreover, an essential condition for the training of a new generation of professionals capable of efficiently and sustainably addressing complex pollution problems, in a way that would not be possible through traditional training methods.

CAI does not replace human expertise, but rather we can consider it as amplifying it. Digital platforms, based on AI/GenAI, allow for a personalization of the learning path, adapting to the specific needs of each learner (future specialist). This approach ensures that specialists are not only informed but also agile, innovative, and well-prepared to use technology as an essential tool in solving environmental problems. The real impact of CAI extends beyond the individual, contributing to a more effective and sustainable approach to pollution problems at the societal level.

References

[1] Wang, J.Z., J.N. Zhen, W.F. Hu, S.C. Chen, I. Lizaga, M. Zeraatpisheh, and X.D. Yang. "Remote sensing of soil degradation: Progress and perspective.” *International Soil and Water Conservation Research* 11, no. 3 (2023): 429-454. DOI10.1016/j.iswcr.2023.03.002.

[2] Jiang, C., H.W. Guo, Y.P. Wei, Z.Y. Yang, X.C. Wang, M.L. Wen, L. Yang, L.L. Zhao, H.Y. Zhang, and P. Zhou. "Ecological restoration is not sufficient for reconciling the trade-off between soil retention and water yield: A contrasting study from a catchment governance perspective.” *Science of the Total Environment* 754 (2021): 142139. DOI10.1016/j.scitotenv.2020.142139.

[3] Ferreira, C.S.S., S. Seifollahi-Aghmiuni, G. Destouni, N. Ghajarnia, and Z. Kalantari. "Soil degradation in the European Mediterranean region: Processes, status and consequences.” *Science of the Total Environment* 805 (2022): 150106. DOI10.1016/j.scitotenv.2021.150106.

[4] Lee, H., K. Sam, F. Coulon, S. De Gisi, M. Notarnicola, and C. Labianca. "Recent developments and prospects of sustainable remediation treatments for major contaminants in soil: A review.” *Science of the Total Environment* 912 (2024): 168769. DOI10.1016/j.scitotenv.2023.168769.

[5] Aparicio, J.D., E.E. Raimondo, J.M. Saez, S.B. Costa-Gutierrez, A. Alvarez, C.S. Benimeli, and M.A. Polti. "The current approach to soil remediation: A review of physicochemical and biological technologies, and the potential of their strategic combination.” *Journal of Environmental Chemical Engineering* 10, no. 2 (2022): 46-57. DOI10.1016/j.jece.2022.107141.

[6] Gu, F., J.P. Zhang, Z.Q. Shen, Y. Li, R.T. Ji, W. Li, L.J. Zhang, J.G. Han, J.M. Xue, and H. Cheng. "A review for recent advances on soil washing remediation technologies.” *Bulletin of Environmental Contamination and Toxicology* 109, no. 4 (2022): 651-658. DOI10.1007/s00128-022-03584-6.

[7] Coman M., and B. Cioruța. *From Human-Environment Interaction to Environmental Informatics / De la interacțiunea om-mediu la informatica mediului*. Cluj-Napoca, AcademicPres Publishing House, 2021.

[8] Cioruța, B.V., and M.A. Coman. *Protecția solurilor și informatica mediului*. Cluj-Napoca, AcademicPres Publishing House, ISBN 630309177-8 CD, 2025.

[9] Cioruța, B.V., and I.E. Cioruța. *Soil Protection and Environmental Informatics*. Cluj-Napoca, AcademicPres Publishing House, ISBN 630309179-2 CD, 2025.

[10] Cioruța, B.V., I.E. Cioruța, M.A. Coman, and A.L. Pop. "Pedagogical Valences of the MIT App Inventor® Platform in Creating Applications for Soil Monitoring and Protection.” *Hidraulica Magazine*, no. 4 (2023): 43-49.

[11] Cioruța, B.V., I.E. Cioruța, M. Sălișcan, A.L. Pop, and M.A. Coman. "My Soil Protection App" - A Mobile-Based Dedicated Environmental Information System - from a User Testing and Validation Perspective.” *Hidraulica Magazine*, no. 1 (2025): 83-91.

[12] Cioruța, B. V., I.E. Cioruța, and A.L. Pop. "From computer-assisted instruction to the challenges of STE(A)M education / De la instruirea asistată de calculator la provocările educației STE(A)M.” In Maier, M. *The use of new technologies in academic instruction - Milestones in the initial and continuing training of teachers / Utilizarea noilor tehnologii în instruirea academică - Repere în formarea inițială și continuă a cadrelor didactice*. GlobeEdit Publishing House, ISBN 978-620-6-79562-9 (2023): 152-173. www.morebooks.shop/shop-ui/shop/product/978-620-6-79562-9.

[13] Ramasundaram, V., S. Grunwald, A. Mangeot, N.B. Comerford, and C.M. Bliss. "Development of an environmental virtual field laboratory." *Computers & Education* 45, no. 1 (2005): 21-34. DOI10.1016/j.compedu.2004.03.002.
[14] Çaliskan, O. "Virtual field trips in education of earth and environmental sciences." *Procedia - Social and Behavioral Sciences* 15 (2011): 3239-3243. DOI10.1016/j.sbspro.2011.04.278.
[15] Krivka, Z., O. Jirák, and Z. Vasícek. "Integrated Development Environment for Virtual Laboratory." Paper presented at the 5th International Technology, Education and Development Conference, Valencia, Spain, March 7-9, 2011.
[16] Kaliszan, D., F. Koczorowski, C. Mazurek, N. Meyer, M. Procyk, T. Rajtar, D. Stoklosa, and M. Stroinski. "Virtual Laboratory of Interactive Teaching - a Live Laboratory for Environmental Science Education." Paper presented at the 4th International Conference of Education, Research and Innovation (ICERI), Madrid, Spain, November 14-16, 2011.
[17] Hinckley, E.L.S., and S. Fendorf. "Field science in the age of online learning: Dynamic instruction of techniques to assess soil physical properties." *Frontiers in Education* 7 (2022): 959776. DOI10.3389/feduc.2022.959776.
[18] Wadoux, A.M.J.C., and A.B. McBratney. "Digital soil science and beyond." *Soil Science Society of America Journal* 85, no. 5 (2021): 1313-1331. DOI10.1002/saj2.20296.
[19] Reyes-Sanchez, L.B. "Teaching soil science: strategies and guarantees for the future." *Spanish Journal of Soil Science* 2, no. 1 (2012): 87-99.
[20] Balseiro-Romero, M., and P.C. Baveye. "Book Review: Soil Pollution: A Hidden Reality." *Frontiers in Environmental Science* 6 (2018): 130. DOI10.3389/fenvs.2018.00130.
[21] Baker, D., T. Selzner, J.H. Göbbert, H. Scharr, M. Riedel, E.T. Hvannberg, A. Schnepf, and D. Zielasko. "Hands-On Plant Root System Reconstruction in Virtual Reality." Paper presented at the 30th ACM Symposium on Virtual Reality Software and Technology VRST '24, Trier, Germany, October 9 - 11, 2024.
[22] Tsai, H.H., X.Y. Hou, C.T. Chang, C.Y. Tsai, P.T. Yu, J.S. Roan, and K.C. Chiou. "Interactive Contents with 360-degree Panorama Virtual Reality for Soil and Water Conservation Outdoor Classroom." Paper presented at the 2020 International Symposium on Educational Technology (ISET), Bangkok, Thailand, August 24-27, 2020.