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OPTIMIZING LEARNING THROUGH SELF-REGULATION, METACOGNITION AND MEMORY TECHNIQUES IN LIFE SCIENCE HIGHER EDUCATION: A THEORETICAL-DESCRIPTIVE ANALYSIS

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Abstract. *The purpose of this article is to analyze and integrate the most effective self-learning strategies, metacognitive approaches and mnemonic techniques applicable in higher agricultural education. In the current educational context, marked by increased autonomy, digitalization and diversification of cognitive styles, students are increasingly responsible for managing their own learning process. The specialized literature highlights the role of self-regulation in improving academic performance, motivation and adaptability (ZIMMERMAN, 1989; PANADERO* & *JÄRVELÄ*, 2015*), while metacognition supports deep learning and knowledge transfer (VEENMAN* et al., *2006). Mnemonics, although often underused in academia, have demonstrated effectiveness in memory consolidation and information retrieval (BELLEZZA, 1981*; L*EVIN, 1993). The study adopts a theoretical-descriptive methodology, based on the analysis of recent scientific articles in the field of Life Sciences and cognitive education. The selected pedagogical strategies were grouped into three main thematic categories: (1) self-regulation of learning in applicative contexts, (2) metacognition in interdisciplinary agricultural learning and (3) mnemonic techniques adapted to Life Science content. In addition, a transversal category was analyzed - the synergies between these strategies and pedagogical applications - to highlight their integrative potential in the formation of an autonomous and reflective Life Science student profile. Each technique is presented with the theoretical foundation, the cognitive mechanisms involved, and practical applications in Life Science university education. The study proposes an integrative approach, combining self-regulation, metacognition and mnemonics in a coherent pedagogical framework. In this sense, the results highlight the synergistic potential of these strategies in shaping an autonomous, reflective and efficient student profile.*

Keywords*: self-regulation of learning, metacognition, mnemonic techniques, Life Science higher education, reflective educational strategies*

INTRODUCTION

In recent decades, educational research has undergone a significant reorientation, from teaching-centered models to paradigms that value active, self-regulated and contextualized learning. This shift in perspective is supported by an increasingly rich scientific literature that explores in depth Self-Regulated Learning (SRL) strategies, metacognition and mnemonic techniques, highlighting their impact on academic performance, motivation and adaptability of students. In particular, these approaches prove essential in applied fields such as Agronomy, where learning involves not only the accumulation of theoretical knowledge, but also the ability to integrate it in practical, dynamic and interdisciplinary contexts.

Self-regulation of learning (Self-Regulated Learning - SRL) is conceptualized as an active and cyclical process through which students set goals, monitor their progress, evaluate their performance, and adjust their strategies based on the results obtained. Tauber and Ariel (2023), in an article published in the *Journal of Intelligence*, provide a synthesis of emerging directions in SRL research. The authors emphasize that self-regulation can no longer be viewed as an isolated skill, but as a complex construct, interconnected with motivation, metacognition,

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and technology use. They highlight four major trends: the integration of SRL with affective processes, the development of digital tools for monitoring learning, methodological diversification, and the emphasis on educational applicability. This holistic approach reflects the need to understand learning not only as a cognitive process, but as a personal and contextualized experience. The holistic view is also supported by RYAN and DECI (2024), who, by updating the self-determination theory, highlight the role of intrinsic motivation in supporting self-regulated learning, especially in educational contexts that value autonomy, responsibility and active student involvement. In the field of Life Sciences, self-regulation is essential for managing complex tasks, such as planning crop rotation, monitoring soil parameters or organizing field activities.

In digital environments, self-regulation becomes a critical factor for academic success. PANADERO and JÄRVELÄ (2015) highlight that students who apply self-regulated learning strategies in digital environments demonstrate deeper cognitive engagement and an increased capacity to adapt to the changing demands of the educational context, especially when learning is supported by collaboration and shared reflection. ORTEGA-RUIPÉREZ and CORREA-GOROSPE (2024) confirm these findings, demonstrating that digitally assisted peer assessment stimulates critical reflection and responsibility in learning, contributing to the development of self-regulation in technologically advanced contexts in higher education. These findings are also corroborated with other research conducted by our working team (DRAGOESCU URLICA & BOGUSŁAWSKA-TAFELSKA, 2021; DRAGOESCU URLICA & KAMBERI, & BOGUSLAWSKA-TAFELSKA, 2022; STEFANOVIC et al, 2021). Also, PSATHAS, CHATZIDAKI and DEMETRIADIS (2023) show that students who apply self-regulated learning strategies in MOOC courses (Massive Open Online Courses) demonstrate deeper cognitive engagement and increased adaptability, which contributes to reducing the risk of dropout in digital educational environments.

Similarly, research by JÄRVELÄ and HADWIN (2013) highlights the need to adapt SRL strategies to the specifics of team learning and the challenges of the digital age. These studies suggest that self-regulation is not only an individual competence, but also a social one, which develops in interaction with others. In this direction, WINNE (2017) proposes a computational model of self-regulated learning, in which the analysis of educational data plays a central role in identifying effective SRL strategies and adapting them to the individual needs of students in digital environments. WIEDBUSCH and AZEVEDO (2024) extend this approach by modeling metacognitive monitoring and the accuracy of learning judgments, highlighting the importance of adaptive feedback in supporting self-regulation. The relevance of metacognition is also highlighted by studies made by other teams of researchers (ARSLAN et al, 2012).

Metacognition, understood as the ability to reflect on one’s own learning process and adjust strategies according to context, is another essential pillar of effective learning. Akamatsu, NAKAYA, and KOIZUMI (2019) demonstrate that metacognitive training increases self-efficacy and supports self-regulation, especially in tasks involving problem solving and decision-making. HADWIN, JÄRVELÄ, and MILLER (2011) extend the concept of metacognition by introducing social co-regulation and self-regulation, highlighting that learning is not only an individual process, but also a distributed one within groups, where self-regulation strategies develop through interaction and joint negotiation. This perspective is particularly relevant in Life Science team projects, where shared reflection and mutual monitoring can improve the quality of decisions and the efficiency of collaboration.

DIGNATH and BÜTTNER (2008) confirms the effectiveness of metacognitive training among STEM (Science, Technology, Engineering, Mathematics) students, demonstrating that it contributes to increasing academic performance and developing critical thinking. According to the analysis by MUIJS and BOKHOVE (2020), metacognition and self-regulation play a key role in improving academic performance. Students who learn to plan, monitor, and evaluate their own learning process are better able to adapt to complex tasks and achieve higher results.

By the same token, VEENMAN et al. (2006) provide a solid theoretical framework for the development of metacognitive skills in science education, showing that metacognition must be actively integrated into the educational process, especially in the exact sciences, through explicit instruction and practical application.SCHRAW and MOSHMAN (1995) complement this view, emphasizing the importance of explicit instruction and guided reflection as essential factors in the development of self-regulation and metacognitive awareness in the educational process. ZOHAR and BARZILAI (2013) confirm that structured metacognitive support (scaffolding) favors students' autonomy and self-assessment capacity, especially in applied educational contexts, where reflection and regulation of the learning process are essential.

Mnemonic techniques are methods of organizing and encoding information that facilitate efficient memorization and retrieval. Although often considered auxiliary, scientific literature reiterates their value in consolidating memory and facilitating strategic learning. Bellezza (1981) and Levin (1993) show that methods such as loci, acronyms, and mind maps not only improve information retention, but also stimulate associative thinking and logical organization of knowledge, contributing to deeper and more structured learning. Studies by SMITH & SCARF (2017) and KARPICKE & BAUERNSCHMIDT (2011) confirm that spaced repetition, applied through apps like Anki, optimizes long-term learning. This method is particularly effective in memorizing scientific vocabulary and complex classifications, such as soil types, plant diseases, or fertilization schedules.

Moreover, DI SANTO et al. (2020) investigate the relationship between working memory training and the use of mnemonic strategies, highlighting that these techniques can be effectively integrated into university training programs. BELLEZZA (1981) explores how mnemonic devices can reduce cognitive load in learning complex content, providing valuable support in the process of encoding and retrieving information. Also, the research of ZIMMERMAN (1989) and PINTRICH (2004) offers an integrative vision of self-regulation, in which motivation, metacognition and cognitive strategies are interdependent and dynamically influence each other, contributing to the development of self-regulated academic performance.

This approach is complemented by the meta-analytic study by RYAN, DI DOMENICO et al. (2022), which demonstrates that intrinsic motivation – that is, the desire to learn out of personal interest, not from external constraint – plays an essential role in initiating and maintaining self-regulated behaviors, supporting cognitive engagement and autonomy in learning. In the same vein, COSTA and REIS (2025) explore motivational teaching techniques that can be integrated into university practice to stimulate active student engagement and support the development of self-regulation in diverse educational contexts.

In conclusion, the recent scientific literature provides a solid theoretical and empirical framework for understanding and applying self-regulation, metacognition and strategic memorization strategies in higher education. These approaches not only optimize academic performance, but also contribute to the formation of students capable of autonomous learning, critical reflection on their own learning process and adaptation to the complex challenges of the professional world. In the field of Life Sciences, where educational and professional decisions have ecological, economic and social implications, these skills become not only useful, but essential for the formation of responsible, innovative and reflective specialists. On the other hand, the integration of these strategies in curriculum design, teacher training and the

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development of digital resources can transform the educational process into an active, reflective and sustainable endeavor.

MATERIALS AND METHODS

To carry out this study, a theoretical-descriptive approach was adopted, with the aim of analyzing and synthesizing the most recent scientific contributions regarding self-learning strategies, metacognition and mnemonic techniques applicable in higher education, with a focus on the field of Life Sciences. The choice of this direction is justified by the specificity of university training in agricultural sciences, which involves the integration of theoretical knowledge with practical skills, interdisciplinarity and adaptability to constantly changing technological and ecological contexts.

The methodology was built on a systematic review of scientific literature published in recognized academic journals, targeting articles that address self-regulated learning, metacognition, and mnemonic techniques in university contexts. Works were selected that provide empirical evidence or theoretical models applicable to the training of students in STEM fields, including agronomy, biotechnology, horticulture, and agricultural engineering.

The selection criteria included:

- Relevance for the development of autonomous learning skills in applied fields;
- Applicability in specific educational contexts (laboratories, field, agricultural practice);
- Methodological originality and contribution to the professional training of future agricultural specialists.

For each source, the types of strategies proposed (cognitive self-regulation, metacognition, mnemonics), the tools used (questionnaires, pedagogical interventions, digital applications) and the results obtained were analyzed. A thematic classification of the strategies was made, with a focus on:

1. Self-regulation of learning in applied contexts (for example: planning field activities, monitoring progress in Life Science projects);
2. Metacognition in interdisciplinary learning (for example: reflection on the process of integrating biological, chemical and technological knowledge);
3. Mnemonic techniques adapted to Life Science content (for example: mind maps for soil classification, acronyms for remembering phytosanitary analysis stages).

This approach allows for a contextualization of the analyzed strategies in relation to the specific needs of Life Science higher education, providing a relevant theoretical framework for curriculum design, teacher training, and supporting active learning in the agricultural field.

RESULTS AND DISCUSSIONS

The analysis of recent literature highlights that self-regulation strategies, metacognition and mnemonic techniques not only optimize academic performance in general, but can also be successfully adapted to the training of students in the field of Life Sciences. The specifics of this field – interdisciplinarity, applicative nature and dependency on contextual observation – require the development of autonomous, reflective and strategic learning skills.

Self-regulation of learning in Life Sciences contexts

Self-regulated learning has emerged as an essential component in the training of future Life Science engineers, playing a decisive role in managing complex tasks, planning field activities and monitoring biological and technological processes in the long term. Recent

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studies confirm that the development of planning, monitoring and self-evaluation capacities significantly contributes to the efficiency of Life Science project management.

TAUBER and ARIEL (2023) point out that students who develop self-regulation skills show more active involvement in applied tasks, such as crop rotation, soil analysis, or integrated pest management. This trend is also supported by research by MUKEMBO et al. (2020), which highlights the effectiveness of Project-Based Learning in stimulating self-regulation and decision-making responsibility in agricultural education.

In addition, the use of digital tools - such as interactive field diaries, agricultural monitoring applications and agronomic planners - facilitates the process of self-regulation, providing students with opportunities for reflection, organization and analysis in real time. JIN et al. (2023) show that the integration of educational technologies supports self-regulation through personalized feedback, visualization of progress and adaptation of learning strategies.

Therefore, self-regulation of learning in Life Science contexts is not limited to the cognitive dimension, but involves an active integration of digital resources, applicative methodologies and metacognitive reflection processes, contributing to the formation of autonomous professionals, capable of managing the complexity of agricultural systems.

Metacognition in interdisciplinary agricultural learning

Metacognition plays a fundamental role in Life Science learning, where students are challenged to integrate knowledge from biology, chemistry, ecology, economics, and technology. The ability to reflect on one's own learning process, for instance identifying difficulties in understanding the interaction between pedoclimatic factors and crop productivity, allows for the adjustment of cognitive strategies and the choice of more effective study methods.

KRIEGER et al. (2022) emphasize that metacognition is an essential predictor of adaptive capacity in complex environments, characterized by multiple and interdependent variables, such as agricultural systems. In an extensive analysis of metacognition in the development of complex skills, the authors highlight the importance of monitoring, reflection, and cognitive control in informed decision-making, especially in interdisciplinary contexts such as crop rotation, soil analysis, or integrated pest management.

Integrating metacognition into Life Science learning requires not only awareness of cognitive processes, but also the ability to adjust them according to the specific requirements of each field. For example, in soil analysis, students must correlate chemical data with biological and technological observations, which implies a continuous reflection on the validity and relevance of the information used. In this sense, metacognition becomes a catalyst for interdisciplinary learning, favoring knowledge transfer and the development of systemic thinking.

Therefore, metacognitive training in Life Science education is not limited to individual self-regulation, but extends towards an integrated understanding of Life Science processes, contributing to the development of professionals capable of managing complexity and uncertainty in the field.

Mnemonic techniques applied in agronomy

Mnemonic techniques are a valuable tool in facilitating the learning of Life Science content, characterized by a high volume of classifications, processes and specific terminology. Adapting these techniques to the particularities of the agricultural field contributes to strengthening working memory and increasing efficiency in the process of retaining and applying knowledge.

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The method of loci, a classic spatial memory strategy, can be used to remember the stages of phytosanitary analysis, by associating each stage with a mental landmark in a familiar route. Acronyms, in turn, facilitate the memorization of soil types, fertilization parameters or phyto-pathological diagnosis stages, providing quick and easy-to-access linguistic landmarks. Mind maps, by visually organizing the relationships between species, diseases, treatments and environmental conditions, support integrative learning and the development of systems thinking.

Recent research supports the effectiveness of these techniques in complex educational contexts. For example, the study by WEINSTEIN et al. (2018) highlights that the deliberate use of concept maps and dual coding (images + text) contributes to deeper learning, especially in content-dense fields such as agronomy.

Therefore, integrating mnemonic techniques into the Life Science curriculum not only optimizes the memorization process, but also supports cognitive self-regulation, providing students with concrete strategies to manage their learning effectively.

Synergies between pedagogical strategies and applications

The integration of self-regulation, metacognition and mnemonic techniques in a coherent pedagogical framework favors the formation of an autonomous, reflective and adaptable Life Science student profile. This integrative approach supports active, contextualised and sustainable learning, in line with the requirements of modern Life Science education.

In an agricultural practice project, students can apply self-regulation to plan field activities, using digital tools to organize tasks and monitor progress (JIN et al., 2023). Metacognition intervenes in evaluating the effectiveness of Life Science interventions, by reflecting on decisions made and adjusting strategies based on results (KRIEGER et al., 2022). In parallel, mnemonic techniques - such as mind maps, acronyms or the method of loci - support the retention and organization of experimental data, facilitating rapid access to relevant information in applicative contexts (PUTNAM et al., 2016; WEINSTEIN et al., 2018).

This synergy between strategies allows the development of systemic thinking, in which the student not only accumulates knowledge, but also integrates, reflects and applies it effectively. In addition, the combination of these methods contributes to the strengthening of cognitive and motivational self-regulation, essential aspects for academic and professional performance in the agricultural field (TAUBER & ARIEL, 2023; MUKEMBO et al., 2020).

Therefore, a pedagogical framework that capitalizes on the complementarity of these strategies not only optimizes the learning process, but also supports the training of specialists capable of managing Life Science complexity with discernment and autonomy.

CONCLUSIONS

The analysis of recent scientific literature convincingly highlights the fact that self-regulated learning strategies, metacognition and mnemonic techniques are not just complementary pedagogical tools, but constitute fundamental pillars of effective, sustainable and reflective learning. In the context of higher education, where the aim is not only to transmit information, but also to form complex skills, these approaches become essential for the development of intellectual autonomy, critical thinking and adaptability.

Self-regulated learning allows students to manage their own educational process in a conscious and strategic way, to set realistic goals, to monitor their progress and to adjust their methods according to the results. This ability is all the more important in the field of Life Sciences, where learning involves integrating theoretical knowledge with field experiences,

http://doi.org/10.59463/RJAS.2025.3.08

making decisions under variable conditions and understanding the interaction between biological, technological and ecological factors.

Metacognition, as a superior form of reflection on one's own thinking, contributes to the development of conscious and adaptive learning. Through metacognitive training, students learn not only "what" to learn, but also "how" and "why" to learn, becoming able to assess their own difficulties, choose appropriate strategies, and optimize their cognitive effort. In agronomy, this ability is crucial for interpreting experimental data, making practical decisions, and learning from experience.

Mnemonic techniques, although often underestimated, provide valuable support in organizing and consolidating information, facilitating efficient memorization and retrieval of knowledge. Applied strategically, they can transform passive learning into an active and creative process, supporting the learning of scientific vocabulary, complex classifications, and Life Science processes.

The integration of these strategies into a coherent pedagogical framework, adapted to the specifics of Life Sciences higher education, allows the formation of graduates capable of learning autonomously, reflecting critically, collaborating effectively and adapting to the professional challenges of the 21st century. In a field where educational and professional decisions have direct implications for the environment, the economy and society, the development of these skills is not only a didactic necessity, but a strategic responsibility.

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