








Research Article

Challenges and Perspectives of Pedagogical Innovation among Life and Earth Sciences Teachers in Moroccan High Schools

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Abstract: This study explores life and earth sciences teachers' perceptions of Pedagogical Innovation (PI) in Morocco and identifies the main factors that hinder its implementation, with the aim of proposing actionable strategies to overcome these barriers and promote innovative teaching practices. A mixed-methods design was employed, combining a questionnaire administered to 319 life and earth sciences teachers from all regional education and training academies, and semi-structured interviews with a purposive sample of innovative teachers. Findings indicate that teachers generally hold positive perceptions of PI, characterized by openness to change, creativity, and professional commitment. Their experiences reveal a strong willingness to improve teaching, enhance student engagement, and adopt active and technology supported approaches, underscoring the potential for innovation when institutional and professional conditions are supportive. To address implementation barriers, the study recommends a coherent, system wide strategy that includes curriculum reform aligned with societal and student needs, and the integration of well-funded, innovative pedagogical projects. Strengthening teachers' capacities through continuous professional development, recognizing and rewarding innovative practices, and establishing collaborative communities of practice (both face to face and online) are essential for sustaining innovation over time. Fostering an institutional culture of innovation also requires recognizing teachers as co-constructors of pedagogical change. Creating platforms, workshops, and competitions to share innovative experiences can enhance motivation, peer learning, and collective reflection. Future research should adopt multi methodological and longitudinal designs, including classroom observations, to better understand how pedagogical innovations evolve and their long-term impact on science education.

Keywords: innovative pedagogy, teacher, high school, challenge, perspective

1. Introduction

Pedagogical Innovation (PI) has become a major concern in education over the past fifty years (Aloui & Bencherqui, 2022; Carvalho et al., 2021), due to growing competition between educational institutions, the constant evolution of teaching tools and materials, and the changing social and extra-academic contexts of student learning (Lison

et al., 2014).

Innovation has been defined in various ways, including as a convergence of ideas, practices and outcomes, incorporating steps such as problem identification, hypothesis formation and testing, modification and final resolution (Rerke et al., 2020). It has also been closely associated with technology integration (Wei et al., 2025), sometimes leading to confusion between pedagogical innovation and technological innovation, with the terms used interchangeably. Whereas innovation introduces new elements in a specific context, the integration of Information and Communication Technologies (ICT) represents a dynamic process generating a series of transformations (Sotiropoulos et al., 2025). Technological innovation has indeed been a major focus of research both internationally (Boticki et al., 2015) and nationally (Benfares et al., 2015; Nafidi et al., 2018).

The teaching and learning of life and earth sciences present a multifaceted challenge, encompassing epistemological, didactic, and sociocultural dimensions (Boilevin, 2013; Ravanis, 2010). These complexities are particularly pronounced in biology, given the inherent complexity and abstract nature of living systems. Consequently, biology teachers and students face unique challenges requiring significant pedagogical innovation in teaching and learning processes (Owen, 2016), ideally within a constructivist framework (Bächtold, 2012; Coquidé-Cantor et al., 2009; Ghariz et al., 2023).

Crucially, any innovative change depends on the commitment of teachers (Jnah & Hanini, 2024; Nancy et al., 2020). Thus, teachers are expected to adopt advanced pedagogies to improve the teaching and learning process (Budirahayu & Saud, 2023). Studies have shown that the ongoing development of teachers' capacity for pedagogical innovation and the development of more innovative teaching methods and techniques are essential to improving student learning outcomes (Cui & Yin, 2023). However, despite pedagogical innovation is an essential lever for improving the teaching and learning process (Carvalho et al., 2021), existing research has mainly focused on technological PI, and few studies have explored the innovation of pedagogical practices in the life and earth sciences (Assimi et al., 2023; El Fadel, 2025; Karolčík & Marková, 2025; Kivunja, 2014; Shettigar et al., 2025), particularly in some countries such as Morocco.

Pedagogical innovation refers to the intentional introduction of new changes in methods, tools, or systems to improve learning, in line with identified needs (Barčíková, 2023). However, recent work distinguishes between technological innovations (digital, online resources), didactic-pedagogical innovations (renewed approaches in life and earth sciences), and organizational innovations (support, tutoring, teamwork) (Barčíková, 2023; Boukarai et al., 2025). In science education, innovative strategies include differentiation, remediation, complex tasks, and individualized monitoring to support struggling learners and strengthen their engagement (Boukarai et al., 2025). These approaches highlight an evolving systemic process, linking the transformation of practices, the reorganization of support, and adaptation to institutional constraints (Barčíková, 2023; Boukarai et al., 2025).

Moroccan studies on science education highlight various innovative initiatives, including the integration of digital technologies and active and participatory teaching methods, but also point to limitations related to insufficient teacher training, lack of resources, and resistance to change (Lahrou & Boudad, 2025). Several studies have demonstrated that learning difficulties in Earth Sciences are principally linked to the comprehension of temporal and spatial scales (Ait Bassou et al., 2023). According to academic studies of teachers, some of whom have trained in biology and others in geology, there are those among them who become demotivated to teach geological knowledge to learners. In addition, the limited capacity for abstraction of unmotivated learners and their insufficient prerequisites in these sciences (Chakour et al., 2019). Furthermore, research has highlighted other constraints that hinder the proper and effective implementation of life science experiments. It has confirmed the existence of technical, pedagogical, and ethical constraints, as well as epistemological constraints (related to the nature of the subject matter and teaching practices). These constraints deprive learners of any sensorimotor investigative attitude and alter the experimental nature of life science teaching (Bouzit et al., 2023). Therefore, in order to improve students' learning processes, teachers need special attention to help them improve the skills necessary to put the subject matter taught into innovative, research-oriented perspectives (Ammar et al., 2024).

Hence, this research aims to help life and earth sciences teachers innovate their teaching practices and respond to the challenges of teaching disciplinary concepts. The main research question states on the issue of how do life and earth sciences teachers' conceptions regarding pedagogical innovation in their practices for teaching disciplinary concepts, articulated as follows:

- What are teachers' perceptions and motivations regarding pedagogical innovations, and how do these perceptions influence their adoption of innovative teaching strategies?

- How do teachers describe their experience and perceived impact of using pedagogical innovations in their teaching practices?

- What obstacles do life and science teachers face in implementing pedagogical innovations, and how do these obstacles affect their motivation and expectations for innovation?

This research will provide a better understanding of the processes involved in adopting and integrating pedagogical innovations, with a view to improving their implementation.

2. Methodology

2.1 Research design

In this research, we used a mixed-methods approach that included quantitative data collection (questionnaire survey), followed by a qualitative data collection phase (semi-structured interviews) (Green et al., 2015). The adoption of a mixed-method approach for this study made it possible to develop a comprehensive question that integrates a quantitative approach (perceptions, opinions, motivation, and obstacles via surveys) and a qualitative approach concerning their experiences, as an introspective approach aimed at deepening the quantitative results in order to obtain reliable information on the real obstacles encountered by teachers that affect the implementation of pedagogical innovation (Bellet et al., 2023; Creswell & Creswell, 2017; Ramírez-Montoya & Lugo Ocando, 2020).

2.2 Sample characteristics

This study focused on public high school life and earth sciences teachers in Morocco. They worked in both urban and rural public schools, with almost three-quarters of them teaching at secondary level and just over a quarter at the middle school level. Our survey targeted 450 participants. We received 319 responses, representing a participation rate of 71%.

Table 1. Sample characteristics

Characteristic	Category	Percentage
Gender	Female	37.6%
	Male	62.4%
Years of experience	Less than 6 years	15.4%
	Between 6 and 10 years	33.5%
	More than 10 years	51.1%
Professional training	Regional Center for Education and Training Professions (CRMEF)	45.5%
	Higher Normal School (ENS)	25.7%
	Regional Pedagogical Center (CPR)	11%
	Aggregation cycle	4.1%
	Direct recruitment	13.7%

As shown in Table 1, the majority were men 62.4% versus 37.6% of women. According to the "Recueil Statistique

de l'Éducation 2022-2023", published by the Ministry of National Education, the percentage of female teachers in secondary education (qualifying) is approximately 38% (see detailed Tables by cycle). This official figure is, in fact, remarkably consistent with this sample (37.6% women) (Ministère de l'Éducation Nationale, du Préscolaire et des Sports, 2023).

84.6% of participants had at least 6 years of experience, over half had more than 10 years of teaching experience (51.1%), and 86.3% had attended professional teaching training courses at the Regional Center for Education and Training Professions (CRMEF), Higher Normal School (ENS), Regional Pedagogical Center (CPR) and Aggregation cycle.

To ensure the representativeness of the sample, a stratified sampling strategy was employed, taking into account the distribution of the population in the different Regional Education and Training Academies (RAET) in Morocco (Figure 1).

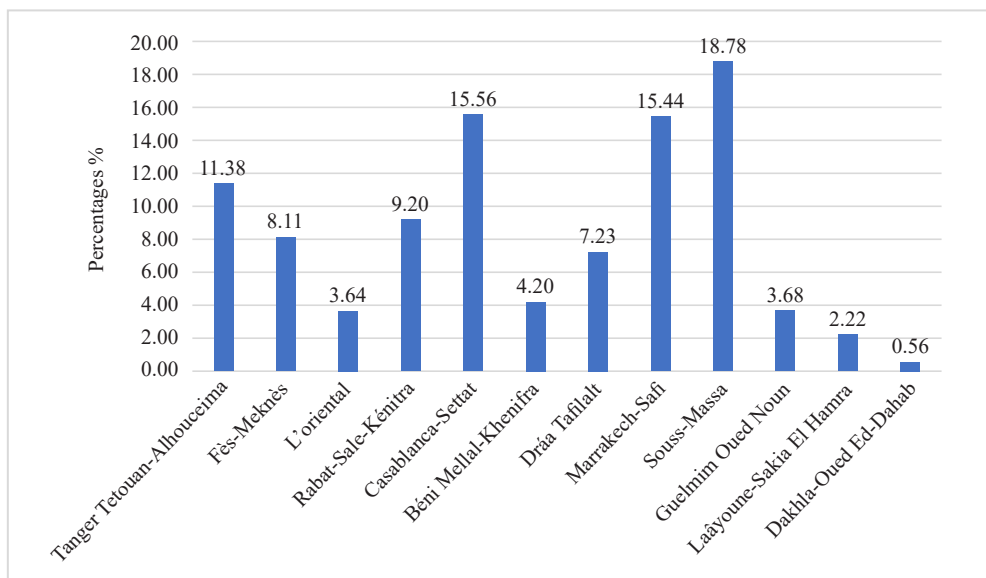


Figure 1. Distribution of the sample according to the different RAET in Morocco

2.3 Data collection

This study used two data collection methods: after using a questionnaire and in order to gain a more nuanced understanding of teachers' perceptions and to supplement the quantitative data collected via the questionnaire, we opted to conduct semi-structured interviews.

Questionnaire: It was developed and distributed remotely using Google Forms. This method was chosen because it is economical and is an easy-to-use tool to efficiently reach a geographically dispersed sample across all Regional Academies of Education and Training (AREFs), the speed and effectiveness of data gathering, and the optimization of quantitative analysis. The design of the questionnaire was based on a review of the relevant literature (Kelly et al., 2023). This tool was validated by specialists in didactics and pedagogical innovation from the Research Team in Educational Engineering and Science Teaching (ERIPDS) at ENS, Université Abdelmalek Essaâdi, Morocco, and the Laboratory of Science and Technology Research (LRST) at the Higher School of Education and Training (ESEF), Ibn Zohr University, Morocco, who confirmed the consistency and relevance of the questions to the study objectives. A pilot test was then carried out with a pre-experimental group ($n = 30$). Cronbach's alpha reliability coefficient was calculated at 0.848. This indicates a high level of internal item consistency and confirms the scale's acceptable reliability.

The questionnaire included 23 questions in two sections. The first contained eight questions on teachers' personal and professional information. The second had seven questions—some using a 4-point Likert scale (1: Strongly disagree; 2: Disagree; 3: Agree; 4: Strongly agree) and others multiple-choice—to assess perceptions of pedagogical innovation.

These covered its nature (Q1), related aspects of PI used by teachers in the classroom (Q2), the conditions of PI (Q3), its role (Q4), its characteristics (Q5), barriers to its practice (Q6a and Q6b), and the types of support needed to develop innovative pedagogical practices (Q7).

Semi-structured Interviews: It were conducted with 10 teachers (2 women and 8 men) who teach life and earth sciences and have received national or regional awards for Pedagogical Innovation. A semi-structured interview program was used for data collection (Pin, 2023). The open-ended interview questions covered four main themes related to PI: (1) motivation, (2) practices, (3) obstacles and (4) impacts. Each interview lasted between 30 and 40 minutes. At the start of each interview, the purpose of the study was briefly explained, and guiding questions were used to focus the conversation.

Ethical considerations: All participants have received informed consent and are fully aware of what is expected of them in this research. They have been assured of the anonymity and confidentiality of all data collected. Participants were also informed that they can refuse to participate in the survey, this fostered a climate of trust and enabled us to collect reliable data. These participants agreed to take part in this research without any pressure.

2.4 Data analysis

Quantitative data were analyzed using SPSS software for the analysis of results and Excel after categorization of responses. Qualitative data from the interviews were analyzed using a thematic approach (Wanlin, 2007) involving categorization in the form of headings grouping elements with common characteristics (Bardin, 2013). This analysis enabled us to reconstruct teachers' discourses and identify their positions on pedagogical innovation.

3. Results

3.1 Teachers' perceptions, motivations, and views on pedagogical innovations and their role in education

3.1.1 Teachers' perceptions of PI

The results presented in Figure 2 reveal that the majority of teachers surveyed (86%) recognize pedagogical innovation as a continuous process of improving teaching practices, and see it as a tool for meeting the needs of 21st century students (83%). Also, 62% of respondents confirm that PI is limited to the use of new technologies in teaching.

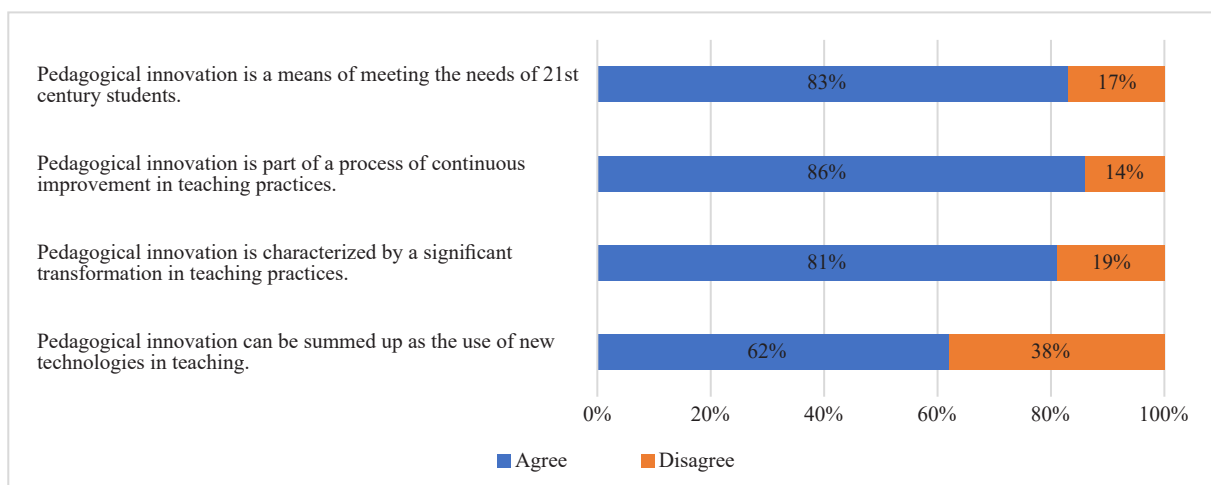


Figure 2. Teachers' perceptions of pedagogical innovation

3.1.2 Teachers' views on the role of pedagogical innovation

According to Figure 3, the majority of teachers perceive pedagogical innovation as a means of improving student learning (90%) and meeting their needs (84%), while it also enhances their enjoyment of teaching (87%). What's more, almost three-quarters of teachers see this innovation as helping to determine student success (70%).

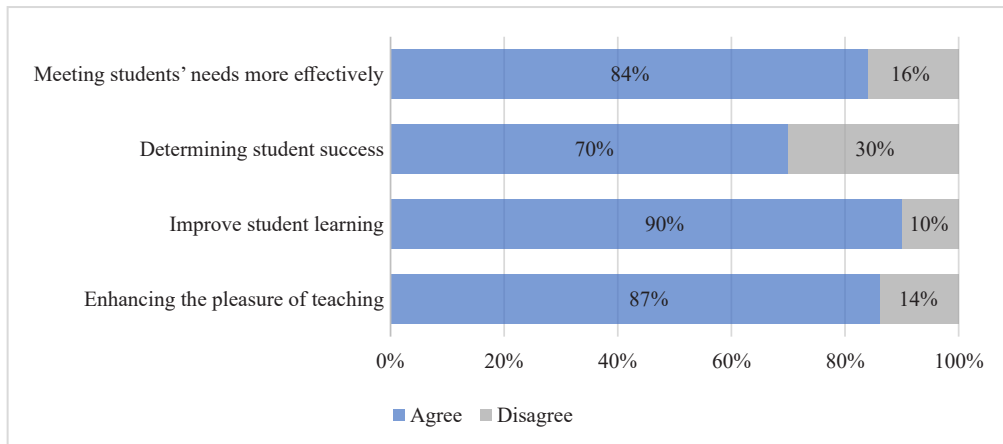


Figure 3. Teachers' answers on the role of pedagogical innovation

3.1.3 Teachers' motivations for innovation

Table 2. The types of motivation that drive teachers to innovate

Motivation types	Edited interviewer's transcripts
Intrinsic motivation for continuous improvement	<p>"My interest in PI emerges from an intrinsic motivation"</p> <p>"To search for new teaching methods"</p> <p>"What pushed me to be interested in PI is my continuous search for improvement, of course, and the diversification of teaching methods"</p>
Influence of the pedagogical international context	<p>"My first contact with PI was through YouTube videos of active classrooms in the USA and Scandinavian countries"</p> <p>"My interest in PI was born from a comparison of our teaching and learning methods with those of Western countries"</p> <p>"The interest started through attending conferences and workshops to share educational experiences"</p>
Membership in innovative teachers' associations	<p>"Participation in conferences and workshops have contributed to exchanges of new and useful ideas for the development of support networks"</p> <p>"Workshops are organized by the association of innovative teachers in Morocco, of which I am already an active member"</p>
Response to field challenges	<p>"The first trigger event was when we changed the teaching language of life and earth sciences. The 2nd trigger event was during COVID and remote learning"</p> <p>"What really pushed me to be interested in PI was the assignment conditions, as a teacher, I was assigned in a rural area"</p>
Student-centered focus	<p>"I aimed to transform this situation to have a significant impact on my learners"</p> <p>"To motivate students"</p> <p>"To cultivate self-directed learning"</p>

By analyzing the discourse of the teachers we interviewed, we were able to identify five categories of motivation driving them to innovate (Table 2). Teachers' interest in PI is mainly intrinsic, with the expression of a strong desire to improve their practices and diversify their teaching methods. This intrinsic motivation is also reinforced by comparison with innovative practices in other countries. Participation in conferences and workshops has also contributed to the exchange of new ideas and the development of support networks. Finally, the teachers were faced with a variety of

challenges, including changing the language of instruction, distance learning during the COVID-19 pandemic and difficult teaching conditions.

3.2 Teachers' adoption of innovative teaching strategies and perceptions of their pedagogical impact

3.2.1 Teachers' adoption of various innovative teaching strategies

The results in Figure 4 reveal distinct trends in teachers' adoption of various innovative practices according to teaching approaches, with more than four out of five using problem-based learning (84.30%), an average of over two-thirds integrating formative assessment (68%) and Hybrid learning (61.40%). However, 47% of teachers rely on placement tests and 44.50% use active pedagogy. Teachers also classify their objectives according to Bloom's taxonomy (29.5%), pedagogical alignment (21%) and e-learning (13.50%).

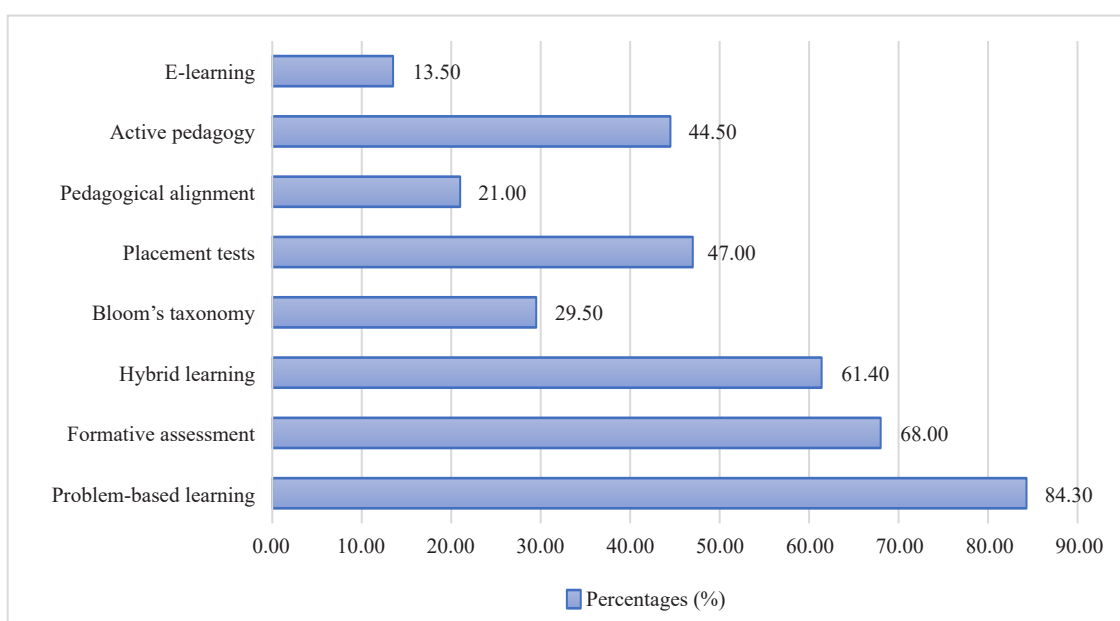


Figure 4. Frequency of use of various pedagogical and didactic practices perceived as innovative by teachers
 * The total exceeds 100% because some teachers selected more than one option.

3.2.2 Teachers' perception on the impact of their use of pedagogical innovations

Analysis of the results below (Table 3) shows that the pedagogical innovation has benefits for students, grouped into five categories: student engagement, academic performance, skills development, impact on students with learning difficulties and learner-centeredness. In addition, it develops students' motivation and interest in their scientific discipline. For example, life and earth science teachers report that it leads to better achievement of learning objectives, even for concepts previously considered difficult. What's more, it enables students to achieve better results on assessments, even if they include complex exercises. Teachers testify that all students, including those with learning difficulties, who have benefited from innovative teaching methods have shown greater class involvement, better attendance and higher marks. Teachers report that pedagogical innovation is student-centered, enabling students to become more autonomous and skilled in collaboration, creativity and problem-solving.

Table 3. Teachers' answers about the impact of their use of pedagogical innovations

Categories	Edited interviewer's transcripts
Student engagement	"Students are more active, engaged, and participate more in class" "Student attendance rates and their attitudes towards school have improved" "PI has sparked students' interest in life and earth sciences " "Satisfaction surveys are used to evaluate each activity"
Academic performance	"A remarkable evolution has been recorded regarding the level of learners" "Through the final result of their proposed project and their answers to the proposed exercises" "Through the scores obtained in the activities"
Skills development	"In the short term, we can adopt pre and post-tests, and in the long term, students become more autonomous" "Students who succeed in difficult thinking exercises" "The student develops autonomy and creativity"
Impact on students with learning difficulties	"Repeaters have confirmed that the new teaching methods have made a real difference for them" "Through innovation, I've been able to successfully teach challenging topics to students who previously struggled"
Student-centered	"I aimed to transform this situation to have a significant impact on my learners" "To motivate students" "To cultivate self-directed learning"

3.3 Implementation challenges and future prospects of pedagogical innovation among life and science teachers

3.3.1 Obstacles to the implementation of pedagogical innovation among life and earth science teachers

Analysis of Figure 5 shows that more than 4 out of 5 teachers reported a lack of training (89%) and appropriate teaching materials (computers, software, digital resources) needed to implement innovative activities (86%). Also 72% reported overwork and lack of time. Conversely, more than half the respondents noted that students can be reluctant to adopt new teaching methods (57%).

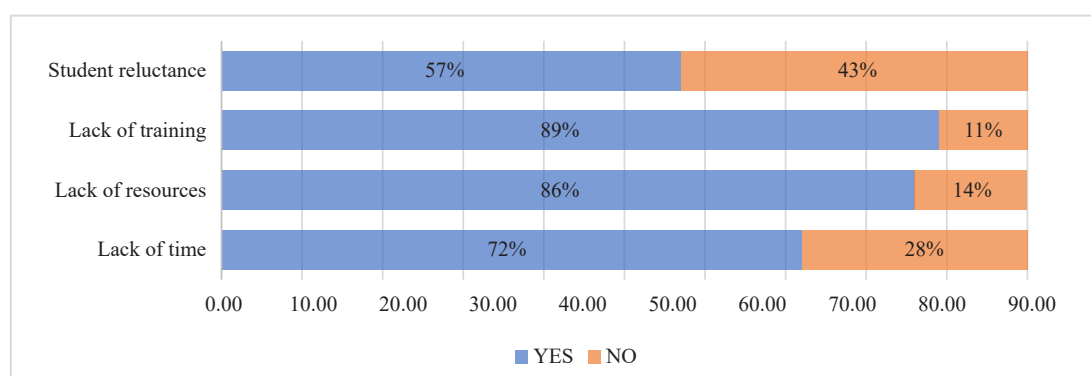


Figure 5. Life and earth science teachers' responses to obstacles to implementing pedagogical innovation

In addition, Table 4 below shows the results of responses to a complementary open-ended question on other obstacles to pedagogical innovation. The analysis reveals numerous interconnected obstacles, concerning teachers, students, curricula, material resources and the institutional context. The classification of these obstacles into several categories reveals that the majority of obstacles are linked to the educational system and resources (overloaded curricula, lack of ongoing teacher training, poorly supported pedagogical teams, unfavorable evaluation systems, and

absence of necessary technological tools and equipment) (68%). Moreover, the two categories of student-related and teacher-related obstacles each account for 16%, or 32% in total.

Table 4. Classification of obstacles hindering teachers' Implementation of pedagogical innovation

Category	Obstacles	Description	Percentages
System-related Factors	Overloaded and rigid curriculum	Excessive content leaves limited time for creative, student-centered approaches.	46%
	Lack of continuous teacher training	Insufficient support for teachers to acquire new skills and implement innovative practices.	
	Under-supported pedagogical teams	Lack of institutional support and recognition discourages innovative initiatives.	
	Results-oriented evaluation	Normative evaluation practices discourage risk-taking and experimentation.	
Resources-related Factors	Lack of materials and infrastructure	Schools lack necessary technology and equipment for active pedagogies.	22%
Student and Environment-related Factors	Student heterogeneity	Diverse student profiles within classes complicate differentiated instruction.	16%
	Lack of student motivation	Factors like language of instruction, content relevance, and personal difficulties affect motivation.	
	Socioeconomic context	Social inequalities influence student resources and opportunities.	
Teacher-related Factors	Resistance to change	Reluctance to adopt new practices due to fear of failure or attachment to traditional methods.	16%
	Lack of recognition	Feeling undervalued can hinder engagement in innovative projects.	
	Excessive workload	Overburdened with administrative tasks, reducing time for lesson preparation and pedagogical innovation.	

3.3.2 The expectations and prospects of pedagogical innovation in the deployment of innovative teaching practices

After categorizing the teachers' responses (Table 5), the analysis shows that, in order to develop innovative teaching practices, the teachers list among the levers; their need for training to implement and reinforce pedagogical innovation (40%), their need for varied, quality teaching resources to enrich their practices (30%), pedagogical support and coaching to implement new practices and overcome difficulties (25%) and the sharing and exchange of experiences between teachers as well as collaboration between them (15%).

Table 5. Teachers' perspectives on levers for promoting innovative teaching practices

Levers for developing innovative teaching practices	Percentages
Training	40%
Pedagogical Resources	30%
Pedagogical Support	25%
Teacher Exchanges	15%

* The total exceeds 100% because some teachers selected more than one option.

Regarding expectations for the future of PI in science and/or life and earth science education, teachers suggested the need for political will, support for new teachers, training for all teachers, competitions to encourage innovative teachers, the creation of a favorable environment for PI, the sharing of validated experiences and the awarding of the best grants to innovative institutions, and the recognition and appreciation of initiatives by peers and the administration.

4. Discussion

Analysis of the results of this study using mixed methods reveals that life and earth science teachers in Moroccan high schools have a generally positive perception of and motivation toward PI. The quantitative results highlight a broad consensus that innovation improves the quality of teaching and student engagement (Purohit & Purohit, 2024), while the qualitative observations add an extra dimension by showing how teachers internalize and experience PI in their daily practices. This dual perspective supports the idea that PI is perceived not only as a technical improvement, but also as a significant professional and personal transformation.

The analysis of teachers' perceptions, motivations, and experience of innovation shows that: quantitatively, most teachers associate PI with improved learning outcomes, professional satisfaction, and adherence to student-centered teaching paradigms (Kelly et al., 2023; Viau, 2009; Walder, 2017). Qualitatively, teachers' narratives describe innovation as a path to pedagogical empowerment, moving beyond traditional rote learning methods toward problem solving, creativity, and critical thinking (Tricot, 2017). In addition, teachers emphasize that experimenting with active, research-based strategies has reshaped the dynamics of their classrooms and promoted student autonomy. Their experiences reflect intrinsic motivation rooted in curiosity, selflessness, and professional pride rather than external incentives. This resonates with Fullan's (2021) classification of innovation triggers, particularly personal motivation, institutional context, and social expectations. However, some teachers classify standard teaching tools such as Bloom's taxonomy or diagnostic/formative assessments as "innovations" due to limited continuing education and subjective novelty in underfunded Moroccan secondary school contexts (Laabidi, 2022). This misclassification risks conceptual confusion, as these tools represent fundamental curriculum requirements rather than true innovations (Benjelloun, 2019). Targeted training would help distinguish basic skills from actual progress.

With regard to the adoption, impact, and perceived value of pedagogical innovations, quantitative data show that adoption rates for innovative strategies vary depending on school resources and teacher experience. Nevertheless, most respondents indicate that implementing pedagogical innovations leads to increased student motivation and participation. Moreover, qualitative responses reveal the subjective experience behind these figures: teachers often describe increased motivation and improved classroom interactions, even if this is sometimes accompanied by uncertainty and hesitation due to trial and error. Teachers perceive concrete improvements in students' self-confidence, collaboration, and problem-solving skills, which is consistent with previous studies linking innovative practices to academic outcomes (Yusmaningsih et al., 2024). However, many also mention the emotional work and ongoing effort required to support innovation, which is a repetitive and reflective process rather than a fixed achievement (Messmann et al., 2022). This experiential aspect illustrates the lived dimension of innovation that quantifiable measures alone cannot capture.

Data on challenges, constraints, and prospects show that both methodological approaches converge in identifying the obstacles that hinder the implementation of IP. Quantitative results highlight structural barriers such as time constraints, lack of materials, and inadequate training (Awang et al., 2025), while qualitative interviews illustrate the human experience of these difficulties. Teachers describe their frustration with overloaded curricula, rigid assessment systems, and limited institutional recognition of their innovation efforts (Bouzit et al., 2023). Despite these frustrations, most teachers remain optimistic and express a collective call for institutional and collegial support. They consider collaboration with peers and administrative support to be essential levers for sustainable innovation (Budirahayu & Saud, 2023; Cui & Yin, 2023). Teachers also emphasize that innovation thrives in a culture where experimentation is valued and supported at the policy level (Palmer & Giering, 2024). In this way, recognition of the shared experience of constraints and aspirations highlights the importance of a community of practice model for professional learning, in which teachers co-construct innovation through dialogue, mutual support, and shared reflection.

Overall, the quantitative and qualitative results paint a picture of a professional culture in transition. Quantitative indicators confirm the widespread appreciation of the relevance of IP, while qualitative narratives reveal that teachers' commitment to innovation is based on identity, the search for meaning, and relational dynamics. Teachers do not adopt

innovation simply because it is institutionalized, but because it corresponds to their values and pedagogical vision. This integrative understanding shifts the debate from “innovation as technical reform” to “innovation as lived and negotiated practice.” To support teachers, structural facilitators (resources, training, political support) must therefore be combined with affective and moral dimensions such as recognition, exchanges between colleagues, and professional autonomy (Cai & Zhu, 2022).

5. Conclusions

PI represents a major challenge for education. Although the obstacles identified are numerous and complex, they can be overcome by implementing targeted actions and fostering close collaboration between all players in the school ecosystem. Indeed, the results of our research reveal a wide range of perceptions of PI among teachers, highlighting a willingness to change, an openness to new practices and a creative spirit. Certain results also indicate confusion between pedagogical innovation and technological innovation; this contextual element warrants dedicated exploration in future studies. However, it is possible to overcome these obstacles through measures such as: a global and coordinated approach involving all the players in education, a reform of curricula adapted to the needs of students and the evolution of society, including innovative projects, ensuring all the necessary funding and resources, whether pedagogical, digital or material. Upgrading and strengthening the teaching profession through ongoing training, recognizing and rewarding teachers’ innovations, and promoting collaborative approaches by creating spaces and environments for sharing their innovative experiences, conducive to group work and the organization of competitions, workshops, and other face-to-face or online sharing events. It is recommended that school stakeholders be mobilized to promote collaboration via platforms, competitions, and online sharing in order to institutionalize sustainable cultures of innovation. Future multi-methodological research, incorporating classroom observations and longitudinal follow-up, will enable interventions in science education to be refined.

The findings of this research should be viewed in light of certain methodological limitations: teachers’ responses provide valuable insights but remain inherently subjective, influenced by individual experiences and contextual factors such as disparities in access to teaching materials and resources. Digital questionnaire distribution via Google Forms introduced selection bias, likely excluding less digitally familiar teachers and potentially overestimating PI adoption. Similarly, the qualitative sample ($N = 10$) focused exclusively on award-winning “super-innovators,” biasing findings toward exceptional cases. Absence of classroom observations reduces ecological validity, as all adoption data relies on self-reports. The cross-sectional mixed-methods design offers complementary perspectives but lacks longitudinal depth; future qualitative and long-term studies are needed to track PI evolution across contexts.

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Conflict of interest

All authors declare that they have no conflicts of interest.

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