

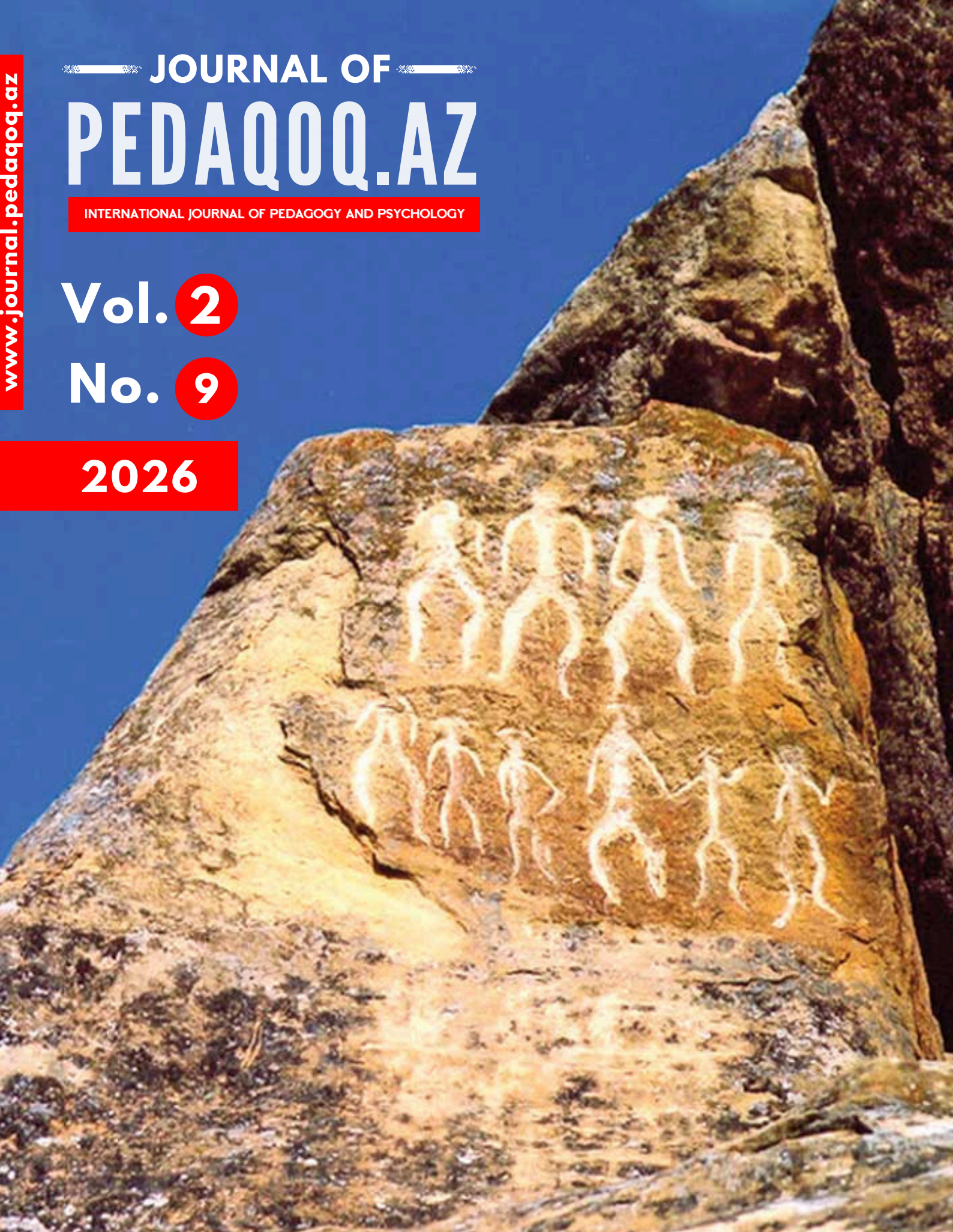
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PSYCHOLOGICAL FACTORS OF PROBLEMATIC INTERNET USE AMONG ADOLESCENTS AND THEIR IMPLICATIONS FOR EDUCATIONAL PRACTICE

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Keywords: problematic Internet use; adolescents; self-regulation; psychological well-being; educational practice; digital behavior; school prevention

Abstract. This study examines psychological and educational aspects of problematic Internet use among adolescents aged 12–16 in the Kyrgyz Republic. The aim of the research is to identify patterns of problematic Internet use and to examine their implications for adolescents' self-regulation, emotional well-being, social interaction, and educational functioning. The empirical study involved 1,250 adolescents enrolled in secondary educational institutions. Problematic Internet use was assessed using the Kimberly Young Internet Addiction Test (IAT) and the Chen Internet Addiction Scale (CIAS). The findings indicate that 54.41% of respondents demonstrated relatively adaptive Internet use, while 41.59% showed persistent problems associated with excessive Internet use and 4.0% demonstrated a high level of addiction risk. The results also revealed difficulties related to time management, emotional dependence, sleep patterns, offline social interaction, and academic engagement. The combined use of IAT and CIAS provides a multidimensional assessment of behavioral and psychological manifestations of problematic Internet use. From an educational perspective, the findings emphasize the importance of early identification of at-risk adolescents and the integration of preventive psychological and pedagogical measures into the school environment. School psychologists, teachers, and parents can play an important role in developing adolescents' digital self-regulation and healthier patterns of Internet use.

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Introduction

The rapid expansion of digital technologies has substantially changed the everyday lives of adolescents. Internet access has become an integral part of learning, communication, entertainment, and social interaction. At the same time, intensive and poorly regulated Internet use may create difficulties in adolescents' daily functioning, particularly when online activities begin to interfere with study, sleep, interpersonal communication, and emotional well-being. Previous research has associated excessive Internet use with difficulties in behavioral control and a range of psychological and social consequences [Kuss et al., 2014; Lopez-Fernandez, 2021]. Adolescence is a particularly important period for examining these patterns because habits of self-regulation, communication, and learning are still developing. Problematic Internet use may therefore be relevant not only to psychological well-being but also to educational functioning. Difficulties in controlling time spent online can compete with school responsibilities, while late-night Internet use may affect sleep and daytime activity. Emotional attachment to online activities and preference for virtual communication may also influence adolescents' interaction with peers, family members, and the school environment [Le et al., 2024]. One of the most widely used approaches to the assessment of problematic Internet behavior is the Internet Addiction Test developed by Kimberly Young [Young, 1998]. The instrument focuses on behavioral manifestations of excessive Internet use and its interference with everyday activities. Another established instrument is the Chen Internet Addiction Scale (CIAS), which assesses several dimensions of problematic Internet use, including compulsive behavior, withdrawal, tolerance, interpersonal and health-related problems, and difficulties in time management [Chen et al., 2003].

The use of these instruments together provides an opportunity to examine both behavioral patterns and their psychological and functional manifestations. For educational institutions, the problem is especially relevant because many consequences

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of excessive Internet use become visible in everyday learning and school life. Difficulties with concentration, sleep, time management, emotional regulation, and offline communication may affect adolescents' engagement with educational activities. Schools can therefore serve not only as settings in which such difficulties are observed but also as environments for early prevention. This increases the importance of cooperation among teachers, school psychologists, adolescents, and parents in promoting balanced patterns of digital behavior.

Research on Internet-related behavioral problems has expanded considerably internationally; however, empirical evidence concerning adolescents in the Kyrgyz Republic remains comparatively limited. Previous research in Kyrgyzstan has nevertheless indicated the presence of problematic Internet use among adolescents and young people [Salmorbekova et al., 2023]. Further analysis is needed to understand how different manifestations of problematic Internet use are distributed among school-age adolescents and what these findings may imply for psychological and educational practice. The aim of this study is to identify the psychological and behavioral patterns of problematic Internet use among adolescents aged 12–16 in the Kyrgyz Republic and to examine their implications for educational practice and school-based prevention.

Main part. Psychological and Educational Dimensions of Problematic Internet Use

Problematic Internet use in adolescence is a complex behavioral phenomenon that cannot be explained solely by the amount of time spent online. Of greater importance is the extent to which Internet use becomes difficult to control and begins to interfere with everyday activities, interpersonal relationships, emotional functioning, and learning. Early studies conceptualized Internet addiction primarily through behavioral symptoms such as loss of control, excessive involvement, withdrawal, and neglect of daily responsibilities [Young, 1998]. Subsequent research has broadened this approach by considering problematic Internet use as a multidimen-

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sional phenomenon involving behavioral, emotional, and functional components [Kuss et al., 2014].

For adolescents, self-regulation is particularly relevant to understanding problematic patterns of Internet use. The digital environment provides continuous access to communication, entertainment, information, and immediate forms of emotional stimulation. Difficulties in regulating these activities may be expressed through spending more time online than originally intended, repeated unsuccessful attempts to reduce Internet use, and postponement of school or everyday responsibilities. In this respect, problematic Internet behavior is closely related to adolescents' ability to organize their time and maintain a balance between online activities and other areas of everyday life.

The Internet Addiction Test (IAT) developed by Young provides a behavioral assessment of these difficulties [Young, 1998]. Its items address such manifestations as excessive time online, neglect of responsibilities, difficulties in limiting Internet use, preference for online activities, and changes in emotional state when Internet access is restricted. The instrument is therefore useful for identifying patterns that may also be relevant to educational functioning, particularly when Internet use begins to compete with study and other daily responsibilities.

The Chen Internet Addiction Scale (CIAS) provides a more differentiated assessment. It includes dimensions related to compulsive Internet use, withdrawal, tolerance, interpersonal and health-related problems, and difficulties with time management [Chen et al., 2003]. These dimensions make it possible to distinguish between the symptoms of problematic Internet involvement and the functional difficulties accompanying them. Later research with adolescents also supported the usefulness of the revised CIAS for examining compulsive use and withdrawal, tolerance, interpersonal and health-related problems, and time-management difficulties [Mak et al., 2014].

The educational significance of these manifestations should not be reduced to

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academic performance alone. Difficulties with time management may affect the organization of homework and daily routines; late-night Internet use may interfere with sleep and daytime activity; and preference for online interaction may influence communication with family members and peers. Previous studies have also reported associations between problematic Internet use and school performance as well as emotional and behavioral difficulties among adolescents [Ko et al., 2005].

At the same time, the results of screening instruments should be interpreted cautiously. IAT and CIAS scores indicate the severity of problematic Internet-use patterns and help identify adolescents who may require closer attention, but questionnaire results alone should not be treated as a clinical diagnosis. This distinction is particularly important in educational settings, where screening is intended primarily to support early identification and prevention rather than to assign clinical labels. From a psychological and educational perspective, the combined application of IAT and CIAS is useful because the two instruments approach problematic Internet use from related but somewhat different perspectives. The IAT provides a general picture of behavioral difficulties associated with Internet use, whereas the CIAS allows a more detailed examination of compulsive symptoms, withdrawal, tolerance, interpersonal and health-related consequences, and time-management problems [Young, 1998; Chen et al., 2003]. Their combined use therefore provides a broader basis for examining adolescents' digital behavior in relation to psychological well-being and educational functioning.

Method

The empirical study was designed to assess patterns of problematic Internet use among adolescents and to identify behavioral and psychological characteristics that may be relevant to educational practice. The study included 1,250 adolescents aged 12–16 years enrolled in secondary educational institutions in the Kyrgyz Republic in 2025.

Participation was voluntary. Adolescents participated with the informed consent

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of their parents or legal guardians. No personally identifiable information was included in the analytical dataset, and the results were analyzed in aggregated form. Participants were informed that participation was voluntary and that they could discontinue their participation. These procedures were intended to protect confidentiality and minimize potential psychological discomfort during data collection.

Two instruments were used. The first was the Internet Addiction Test (IAT) developed by Kimberly Young [Young, 1998]. The IAT contains 20 items assessing behavioral manifestations of problematic Internet use and its interference with everyday activities. Higher total scores indicate greater severity of Internet-related difficulties. In accordance with the scoring approach used in the present study, scores of 20–49 were interpreted as relatively adaptive Internet use, 50–79 as indicating noticeable problems associated with excessive Internet use, and 80–100 as indicating a pronounced level of problematic Internet use [Young, 1998]. The 20-item structure and these conventional score ranges are also reported in applications of the IAT. The second instrument was the Chen Internet Addiction Scale (CIAS) [Chen et al., 2003]. The scale consists of 26 items and assesses several dimensions of problematic Internet behavior, including compulsive use, withdrawal, tolerance, interpersonal and health-related problems, and difficulties with time management. The items are rated on a four-point scale, with higher scores reflecting a greater degree of Internet-related difficulties. The use of the two instruments made it possible to examine problematic Internet use from complementary perspectives. The IAT was used to assess the overall severity of Internet-related behavioral difficulties, whereas the CIAS provided a more differentiated assessment of specific psychological and functional manifestations. The collected responses were converted into numerical scores and entered into a database for statistical analysis. Descriptive statistics and frequency analysis were used to examine the distribution of problematic Internet-use indicators across the sample.

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The results of the two instruments were subsequently compared to identify convergent patterns in adolescents' behavioral and psychological responses.

Results

The findings obtained using the IAT and CIAS indicate that problematic Internet use was present at different levels among the surveyed adolescents. The two instruments revealed a broadly consistent pattern: for most participants, Internet use remained within an adaptive or moderately problematic range, whereas a smaller group demonstrated more pronounced difficulties with behavioral control and everyday functioning. According to the Internet Addiction Test (IAT), 54.41% of the respondents scored within the 23–49-point range. A further 41.59% obtained scores between 50 and 79 points, indicating noticeable problems associated with Internet use, while 4.00% scored 80 points or higher. Thus, almost half of the surveyed adolescents demonstrated some degree of difficulty in regulating their Internet use, although only a relatively small proportion reached the highest score range. These distributions are reported in the original dataset as 54.41%, 41.59%, and 4.0%, respectively.

Table 1. Distribution of Adolescents According to IAT Score Ranges (n = 1,250)

IAT score range	Interpretation used in the study	Participants (%)
23–49	Relatively adaptive Internet use	54.41
50–79	Noticeable problems associated with Internet use	41.59
≥ 80	Pronounced problematic Internet use	4.00
Total		100.00

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The distribution presented in Table 1 shows that problematic Internet use should not be considered a uniform condition among adolescents. The largest group remained within the relatively adaptive range, while a substantial proportion reported difficulties that may require preventive attention. From an educational perspective, the group scoring between 50 and 79 points is particularly relevant because emerging problems with Internet-use regulation may become visible before they develop into more persistent behavioral patterns. Analysis of individual IAT responses provided additional information about these difficulties. 36.3% of adolescents reported that they often or always stayed online longer than intended, while 41.1% frequently found themselves extending Internet use for “a few more minutes.”

Problems related to everyday responsibilities were also evident: 48.5% reported neglecting household duties at least sometimes or often, and 41.1% indicated reduced productivity in study or other activities. Emotional manifestations were also observed: 20.7% often or always experienced a sense of emptiness when offline, while 38.9% reported irritation associated with Internet-use situations. These indicators are contained in the original results and therefore can be retained without introducing additional assumptions.

The CIAS results provided a more differentiated picture of the psychological and functional manifestations of problematic Internet use. Difficulties with time regulation were among the most frequently reported characteristics. 65% of participants partially or fully agreed that they remained online longer than originally intended, while 34% reported unsuccessful attempts to reduce Internet use. Emotional dependence was also apparent: 40% reported distress or discomfort when Internet use had to be interrupted.

Interpersonal and everyday functioning were also affected. 42% of participants reported choosing online activities instead of spending time with friends, and 36% indicated that Internet use reduced communication with family members. Sleep-related difficulties were particularly relevant from a psychological and educational perspective: 32% reported sleeping for fewer than four hours because of Internet use,

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while 42% reported daytime fatigue.

Table 2. *Selected Behavioral and Psychological Manifestations Identified by IAT and CIAS*

Dimension	Indicator	Participants (%)
Time regulation	Staying online longer than intended (CIAS)	65.0
Self-control	Unsuccessful attempts to reduce Internet use (CIAS)	34.0
Emotional response	Distress when Internet use is interrupted (CIAS)	40.0
Social interaction	Online activities instead of spending time with friends (CIAS)	42.0
Family interaction	Reduced communication with family (CIAS)	36.0
Sleep	Fewer than four hours of sleep because of Internet use (CIAS)	32.0
Daytime functioning	Daytime fatigue (CIAS)	42.0
Time regulation	Often/always staying online longer than intended (IAT)	36.3
Time regulation	Extending use for "a few more minutes" (IAT)	41.1

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Daily responsibilities	Neglect of household duties, sometimes/often (IAT)	48.5
Educational functioning	Reduced study/work productivity (IAT)	41.1
Emotional response	Feeling empty when offline, often/always (IAT)	20.7
Emotional response	Irritation related to Internet use (IAT)	38.9

Importantly, percentages obtained from the two instruments should not be interpreted as directly equivalent measures. The IAT and CIAS contain differently formulated items and response categories. Their results are therefore used here to identify converging behavioral patterns rather than to establish direct item-by-item equivalence.

The CIAS subscale scores further demonstrated that problematic Internet use involved several interconnected dimensions. The mean scores were 10.98 for compulsive use (Com), 11.39 for withdrawal (Wit), 9.55 for tolerance (Tol), 15.22 for interpersonal and health-related problems (IH), and 13.86 for time-management problems (TM). The mean score for Internet addiction symptoms (IA-Sym) was 31.84, while the mean score for related problems (IA-RP) was 29.07. The overall mean CIAS score was 60.91.

Table 3. Mean CIAS Scores Among the Surveyed Adolescents

CIAS dimension	Abbreviation	Mean score
Compulsive use	Com	10.98
Withdrawal	Wit	11.39
Tolerance	Tol	9.55

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Interpersonal and health-related problems	IH	15.22
Time-management problems	TM	13.86
Internet addiction symptoms	IA-Sym	31.84
Internet-related problems	IA-RP	29.07
Total CIAS score	CIAS total	60.91

The pattern of CIAS scores suggests that the difficulties reported by adolescents extended beyond the frequency of Internet use itself. Problems involving interpersonal and health-related functioning and time management were prominent components of the overall pattern. When considered together with the IAT findings, the results point to difficulties in self-regulation, emotional responses, sleep, everyday responsibilities, and social interaction.

From an educational perspective, these findings are relevant because several of the identified manifestations are directly connected with adolescents' everyday functioning. Reduced sleep, daytime fatigue, difficulties in controlling online time, and reduced productivity may interfere with participation in educational activities. At the same time, the results do not establish that Internet use itself caused poorer educational outcomes, because the present cross-sectional study did not test causal relationships. Rather, the findings identify behavioral and psychological patterns that warrant attention in school-based prevention and psychological support.

Discussion

The findings of the present study show that problematic Internet use among adolescents in the Kyrgyz Republic is not limited to a small group with highly pronounced symptoms. Although 4.0% of participants reached the highest IAT score

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range, a considerably larger group demonstrated difficulties associated with excessive Internet use. This distinction is important because preventive work in educational settings should not focus exclusively on adolescents with the most severe manifestations. Students experiencing emerging difficulties with time management, emotional regulation, sleep, or everyday responsibilities may also benefit from early psychological and pedagogical support.

The results are consistent with the multidimensional understanding of problematic Internet use proposed in previous research. Young emphasized loss of control, excessive involvement, and interference with everyday activities as important behavioral manifestations [Young, 1998]. The CIAS model further differentiates compulsive use, withdrawal, tolerance, interpersonal and health-related problems, and time-management difficulties [Chen et al., 2003]. In the present study, manifestations belonging to several of these dimensions occurred simultaneously, supporting the view that problematic Internet behavior should not be assessed only through the number of hours adolescents spend online.

Time regulation appears to be particularly relevant. Many respondents reported remaining online longer than intended, while some experienced difficulties when attempting to reduce their Internet use. These findings may reflect limitations in behavioral self-regulation rather than Internet exposure alone. During adolescence, the development of self-control and the organization of daily routines remain important psychological and educational tasks. For this reason, preventive interventions may be more useful when they teach adolescents how to plan online activity and regulate digital habits rather than simply imposing restrictions on Internet access.

The emotional component also deserves attention. Distress when Internet use was interrupted, irritation, and feelings of emptiness when offline were reported by a proportion of respondents. Similar emotional and behavioral manifestations have been considered relevant characteristics of problematic Internet use in previous studies [Kuss et al., 2014; Lopez-Fernandez, 2021]. Nevertheless, these responses should not

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automatically be interpreted as evidence of a mental disorder. Within a school setting, they are more appropriately viewed as indicators that may help psychologists and educators identify adolescents who could benefit from further assessment or support.

Sleep-related findings are also important. Some adolescents reported substantial reductions in sleep associated with Internet use and subsequent daytime fatigue. In educational practice, insufficient sleep and fatigue are relevant because they may affect adolescents' daily routines and capacity to participate effectively in learning activities. However, the cross-sectional design of the present study does not allow a causal conclusion that Internet use itself produced these educational difficulties. The observed relationships should therefore be interpreted as potential areas for psychological and educational attention rather than as demonstrated causal effects.

Another finding concerns interpersonal interaction. Some participants reported choosing online activities over communication with friends or reducing communication with family members. This does not imply that online communication is inherently negative. Digital environments are an important part of contemporary adolescent socialization. The issue becomes relevant when online activity persistently displaces offline relationships or interferes with everyday responsibilities. Such a distinction is important for educational prevention because interventions based solely on restricting technology may fail to address the psychological functions that online activity performs for adolescents.

The combined application of the IAT and CIAS provided complementary information. The IAT identified the overall severity of Internet-related behavioral difficulties, whereas the CIAS allowed these difficulties to be considered in relation to compulsive use, withdrawal, tolerance, interpersonal and health-related problems, and time management [Young, 1998; Chen et al., 2003]. The usefulness of multidimensional assessment is also supported by studies applying the CIAS framework to adolescent populations [Mak et al., 2014]. Thus, the use of both instruments can be particularly in-

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formative for research and screening purposes.

Implications for Educational Practice

The findings have several implications for educational institutions. First, prevention should be directed not only at reducing screen time but also at developing digital self-regulation.

Adolescents need practical skills for organizing study and leisure time, managing notifications and interruptions, maintaining appropriate sleep routines, and recognizing situations in which online activity begins to interfere with everyday responsibilities.

Second, school psychologists may play an important role in early identification. Screening instruments such as the IAT and CIAS can help identify patterns requiring closer attention, but questionnaire scores should not be used independently to assign a clinical diagnosis. Screening should be followed, where necessary, by individual psychological assessment and consultation.

Third, preventive activities should involve teachers and parents. Teachers may observe changes in classroom engagement, fatigue, difficulties with concentration, or completion of educational tasks, while parents are better positioned to observe adolescents' Internet routines outside school. Cooperation between the family and educational institution may therefore provide a more complete understanding of adolescents' digital behavior.

Finally, preventive programs should avoid presenting digital technology exclusively as a source of risk. Internet resources are an established component of education, communication, and adolescents' social lives.

The educational objective should instead be to promote a balanced pattern of use in which digital activity supports learning and communication without consistently displacing sleep, offline interaction, physical activity, and everyday responsibilities.

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Conclusion

The present study examined the psychological and behavioral characteristics of problematic Internet use among 1,250 adolescents aged 12–16 years in the Kyrgyz Republic using the Internet Addiction Test (IAT) and the Chen Internet Addiction Scale (CIAS). The findings demonstrate that problematic Internet use among adolescents is heterogeneous and includes different levels of behavioral and psychological difficulty.

According to the IAT results, 54.41% of participants demonstrated relatively adaptive Internet use, 41.59% showed noticeable problems associated with excessive Internet use, and 4.0% reached the highest score range. The CIAS findings complemented these results by identifying difficulties related to compulsive use, withdrawal, tolerance, interpersonal and health-related functioning, and time management. The overall mean CIAS score was 60.91, with notable scores for interpersonal and health-related problems and difficulties in time management.

The results suggest that the educational significance of problematic Internet use extends beyond the amount of time adolescents spend online. Difficulties with self-regulation, emotional responses, sleep, everyday responsibilities, and offline interaction may influence adolescents' functioning within both family and educational environments. For this reason, prevention should focus not simply on restricting Internet access but on helping adolescents develop more balanced and self-regulated patterns of digital behavior.

Educational institutions can contribute to early prevention by integrating digital self-regulation, responsible Internet use, sleep awareness, and time-management skills into psychological and educational support activities. School psychologists may use standardized screening instruments to identify adolescents who require closer attention, while cooperation with teachers and parents can support earlier recognition of behavioral changes. Screening results, however, should be interpreted as indicators of potential risk rather than as independent clinical diagnoses.

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The study also has several limitations. Its cross-sectional design does not allow causal relationships to be established between problematic Internet use and psychological or educational functioning. The findings are based primarily on adolescents' self-reported responses and may therefore be influenced by individual perceptions and response patterns. In addition, the present analysis does not examine differences according to gender, age group, school characteristics, or specific types of online activity. These factors should be considered in future research.

Further studies may employ longitudinal designs and examine how patterns of Internet use change during adolescence and how they relate to psychological well-being, sleep, educational engagement, and interpersonal relationships over time. Such research would provide a stronger empirical basis for the development of age-appropriate school-based prevention programs.

Overall, the findings support the need for a balanced psychological and educational approach to adolescents' Internet use. Digital technologies are an integral part of contemporary education and social interaction; therefore, the primary objective should not be their restriction, but the development of adolescents' capacity to use them consciously, safely, and in ways compatible with learning, healthy daily routines, and offline social relationships.

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**PSYCHOLOGICAL AND SOCIOLOGICAL INFLUENCES ON SUICIDAL RISK FACTORS
DURING ADOLESCENCE**

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Abstract. Adolescence is a complex and important stage of human development characterized by significant psychological, emotional, behavioural, and social changes. During this period, young people experience changes in their identity, relationships, attitudes, and perception of themselves and the surrounding world. These developmental processes may influence their psychological well-being and ability to cope with different life situations. Adolescents may encounter various personal and social difficulties that increase emotional vulnerability. Psychological distress, difficulties in emotion regulation, stressful experiences, problems in family and peer relationships, social isolation, and challenges within the educational environment can negatively affect their emotional state. The interaction of these factors may become particularly important when adolescents do not receive sufficient understanding and support. The article provides a general analysis of the main psychological and social factors associated with suicide risk among adolescents. Particular attention is given to the relationship between individual psychological characteristics and the influence of family, peers, school, and the wider social environment. The issue is considered from a general perspective, taking into account the complex and multifactorial nature of adolescent behaviour and psychological well-being.

Introduction

Suicide attempts may result from a complex interplay of social, economic, psychological, and moral factors. The prevalence of suicidal behavior has been increasing progressively in recent years. Of particular concern is the apparent decline in the age at which suicidal behavior occurs. The increasing incidence of suicidal thoughts and other forms of suicidal behavior among children and adolescents constitutes a significant public health and psychosocial concern, highlighting the need for greater attention to the psychological, social, and environmental factors that may contribute to such behavior. One in six people are aged 10–19 years. Adolescence is a unique and formative time. Physical and social changes, including exposure to poverty, abuse, or violence, can make adolescents vulnerable to mental health problems. Protecting adolescents from adversity, promoting socio-emotional learning and psychological well-being, and ensuring access to mental health care are critical for their health and well-being during adolescence and adulthood. [World Health Organization [WHO], 2025, para. 1]. It is not possible to determine in advance whether an adolescent will attempt suicide. Certain warning signs and risk factors may indicate an increased risk of suicidal behavior and should therefore be approached with particular caution. Several factors may warrant concern and require careful attention, including:

- A previous suicide attempt;
- The recent loss of a person who was emotionally significant to the adolescent;
- Exposure to any form of violence or abuse within the adolescent's social environment;
- The presence of any psychological or psychiatric disorders;
- Self-harming behavior, even when it is perceived as an attempt to attract attention.

Main part. Suicidal behavior is a complex and multidimensional phenomenon that cannot be attributed to a single, clearly identifiable cause. Rather, it develops through the interaction of various psychological, social, and individual factors. Contemporary scientific perspectives emphasize that suicide risk should be understood not through isolated determinants but through the combined and interrelated influence of multiple risk factors. In recent years, the growing visibility of suicide-related issues in both traditional and social media has further increased the social and scientific relevance of this problem.

Among the psychological factors that may contribute to suicide risk during adolescence, emotional sensitivity and difficulties in emotion regulation are particularly significant. Adolescence represents a developmental stage characterized by substantial changes in personality development, self-perception, social relationships, and emotional functioning. Against this background, some adolescents may experience difficulties in identifying, expressing, and regulating their emotions effectively. When intense emotional experiences remain unexpressed, internal distress is not shared with others, and appropriate psychological support is unavailable, emotional strain may become persistent. Prolonged exposure to such difficulties may negatively affect adolescents' self-perception and contribute to diminished self-confidence and a reduced sense of self-worth.

Social withdrawal and the weakening of interpersonal relationships may also constitute important psychological and social risk factors. Reduced emotional connection with family members, friends, and peers can intensify feelings of loneliness and create the perception that personal difficulties must be managed without adequate support. Such experiences may become more pronounced when accompanied by additional stressors within the family or educational environment. Persistent family

conflict, difficulties in peer relationships, excessive academic expectations, pressure associated with assessment, and fear of failure may undermine emotional stability and adversely affect adolescents' confidence in their own abilities.

Anxiety and depressive symptoms represent additional factors that may substantially influence psychological well-being during adolescence. Persistent worry, fear and negative expectations concerning the future, declining interest in everyday activities, social withdrawal, reduced motivation, sadness, and hopelessness can interfere with daily functioning and social adjustment. When such symptoms persist over time, adolescents may become increasingly disconnected from potential sources of social support, thereby increasing the likelihood that existing emotional difficulties will intensify. Consequently, early identification of psychological distress, appropriate assessment of its severity, and timely access to professional support are important components of suicide prevention among adolescents.

Internal emotional conflicts also require particular attention during adolescence. At this stage of development, individuals attempt to understand their emerging identity, emotions, and personal needs while simultaneously adapting to expectations imposed by family, school, and the broader social environment. A discrepancy between personal needs and external demands may contribute to heightened internal tension. Adolescents who have difficulty communicating their feelings or discussing personal problems may respond by withdrawing from interpersonal relationships and internalizing their distress. Over time, this pattern may contribute to greater psychological strain, intensified emotional suffering, and a diminished sense of personal worth.

Within this context, strengthening adolescents' emotional competencies can be regarded as an important component of preventive intervention. Establishing a

supportive psychosocial environment in which adolescents are able to recognize, express, and regulate their emotions appropriately may enhance their ability to adapt to stressful and challenging life circumstances. Systematic cooperation among families, schools, and psychological support services can also facilitate the early recognition of warning signs and ensure that assistance is tailored to the individual needs of the adolescent. Psychological interventions should therefore extend beyond the reduction of immediate emotional difficulties and include the development of effective coping strategies, emotion-regulation skills, problem-solving abilities, and the capacity to access and utilize available sources of social support.

Another significant area associated with suicide risk concerns the long-term consequences of traumatic experiences and insufficient social support. Exposure to severe or repeated traumatic events during childhood and adolescence may have enduring effects on emotional development and psychological well-being. Such experiences can be associated with reduced feelings of safety, diminished self-confidence, difficulties in establishing trust in interpersonal relationships, and an overall deterioration in perceived quality of life. When children or adolescents who have experienced trauma do not receive sufficient emotional support from family members or other significant individuals, the psychological consequences of these experiences may become more difficult to manage.

Limited access to social and emotional support may further intensify feelings of loneliness and vulnerability among adolescents. Persistent misunderstanding or conflict within the family, difficulties with social adjustment in the school environment, and restricted communication with trusted individuals may influence how adolescents perceive and respond to their problems. Chronic stress and traumatic experiences may gradually deplete psychological resources, increasing feelings of fear, hopelessness,

and social isolation. For this reason, adolescents displaying indicators of elevated risk should have timely access to professional psychological assistance, while efforts should also be made to strengthen their broader support networks across family, school, and peer contexts.

The prevention of suicide risk among adolescents should not be restricted to individual psychological intervention alone. Effective prevention requires a comprehensive and multidimensional approach that addresses individual, family, school, and broader social factors. Promoting open and supportive communication within families, establishing psychologically safe and inclusive educational environments, strengthening school-based psychological services, and implementing programs aimed at improving adolescents' emotional literacy are important components of such an approach. In addition, systematic psychological assessment and continued monitoring of adolescents identified as being at increased risk can facilitate the timely planning and implementation of appropriate interventions. Overall, suicide prevention during adolescence requires a coordinated and sustained strategy that considers not only individual psychological characteristics but also the family, educational, and social systems within which the adolescent develops.

Despite extensive research conducted by psychologists and other scholars, the etiology of suicide cannot be attributed to a single, definitive cause. Rather, suicidal behavior is generally understood as a complex and multifaceted phenomenon shaped by the interplay of psychological, social, biological, and environmental factors. Nevertheless, reports and discussions concerning suicide have become increasingly prevalent in both mass media and social media platforms, making the phenomenon a prominent issue within contemporary public discourse.

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According to the World Health Organization (WHO), an estimated 727,000 people died by suicide in 2021, while many more individuals attempted suicide. The consequences of suicide extend far beyond the loss of life, affecting families, communities, and societies and producing long-term psychological and social impacts on those left behind. Suicide can occur at any stage of life and, in 2021, it ranked as the third leading cause of death among individuals aged 15–29 worldwide (World Health Organization [WHO], 2025).

Conclusion

Suicide risk among adolescents should be understood as a complex phenomenon shaped by the interaction of psychological, emotional, interpersonal, and environmental factors. The analysis indicates that difficulties in emotion regulation, anxiety and depressive symptoms, social withdrawal, traumatic experiences, insufficient social support, and persistent stress may collectively increase adolescents' psychological vulnerability. These factors rarely operate independently; rather, their cumulative and reciprocal effects may intensify emotional distress and reduce an adolescent's ability to cope effectively with challenging life circumstances.

Overall, promoting adolescent mental health requires sustained attention to both risk and protective factors. Creating environments in which young people feel safe, valued, understood, and able to seek help without fear of judgment can contribute significantly to their psychological well-being.

Future research should further examine the interaction between individual vulnerabilities and social-environmental influences, as well as evaluate the effectiveness of culturally appropriate prevention and early-intervention strategies.

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Such evidence may contribute to the development of more targeted, comprehensive, and sustainable approaches to reducing suicide risk among adolescents.

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THE USE OF BIOINDICATORS IN THE FORMATION OF STUDENTS' ECOLOGICAL RESEARCH SKILLS

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Abstract. The formation of students' ecological research skills is an important objective of contemporary biology and environmental education. In this context, the use of bioindicators provides significant methodological opportunities for integrating theoretical ecological knowledge with practical research activities. Bioindicators, including plants, lichens, fungi, microorganisms, aquatic organisms, and other biological communities, can reflect changes in environmental conditions through variations in their abundance, distribution, diversity, physiological characteristics, and community structure. Their application in biology education enables students to investigate real ecological processes and develop essential scientific research competencies. The present study examines the methodological and pedagogical potential of bioindicators in the formation of students' ecological research skills. Particular attention is given to the development of observation, problem identification, research question and hypothesis formulation, field sampling, data collection, classification, quantitative analysis, comparison, interpretation, and evidence-based conclusion-making skills. Bioindicator-based investigations can also contribute to the development of students' critical thinking, scientific reasoning, collaborative abilities, digital competencies, and environmental awareness. The integration of field observations with laboratory investigations, quantitative

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ecological methods, and information technologies creates opportunities for inquiry-based and competency-oriented biology education. At the same time, appropriate selection of bioindicators, standardized sampling procedures, repeated observations, consideration of environmental variability, and critical evaluation of research limitations are essential for ensuring the reliability of student investigations. Overall, the systematic incorporation of bioindicators into biology teaching can transform ecological learning into an active research process and contribute to the development of scientifically literate, environmentally responsible, and critically thinking students capable of understanding and evaluating ecological changes in their surrounding environment.

Introduction

Contemporary environmental challenges, including climate change, biodiversity loss, habitat fragmentation, soil degradation, water pollution, and increasing anthropogenic pressure on natural ecosystems, have created an urgent need to strengthen environmental education and develop students' ecological research competencies. Modern biology education is no longer limited to the transmission of theoretical knowledge about organisms and ecosystems; it increasingly emphasizes students' ability to observe environmental changes, identify ecological relationships, collect and interpret empirical data, formulate hypotheses, and make scientifically justified conclusions. In this context, the development of ecological research skills represents one of the important components of science education aimed at preparing students to understand complex environmental processes and participate responsibly in environmental protection. Effective biology teaching should therefore provide opportunities for students to investigate real ecological problems using accessible scientific methods and biological indicators.

Bioindicators occupy a particularly important position among the methodological tools that can be incorporated into ecological education. A bioindicator is a biological organism, community, or biological response whose presence, absence, abundance, distribution, physiological condition, or changes in population structure can provide information about the characteristics and quality of an environment.

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Plants, lichens, mosses, algae, fungi, microorganisms, invertebrates, and certain vertebrate species can serve as indicators of environmental conditions because their biological characteristics respond to changes in ecological factors. Unlike many purely instrumental measurements, bioindication provides students with an opportunity to examine environmental quality through observable biological responses and to establish connections between environmental factors and changes occurring at the organismal or community level [Chandel, Sharma, & Kumar, 2024].

The educational value of bioindicators is associated not only with their application in environmental assessment but also with their potential to transform the learning process into an inquiry-based scientific activity. When students investigate bioindicators in their local environment, they are able to move beyond passive acquisition of ecological concepts and engage directly in observation, sampling, classification, comparison, measurement, documentation, and interpretation. Such activities create conditions for integrating theoretical biological knowledge with practical research experience. For example, students may compare the distribution of lichens in areas characterized by different levels of urbanization, investigate plant species composition along an environmental gradient, examine aquatic macroinvertebrate communities as indicators of water quality, or assess changes in soil organisms in areas subjected to different anthropogenic influences. Through these investigations, ecological concepts become associated with real environmental phenomena that students can observe and analyze.

The formation of ecological research skills requires a systematic combination of cognitive, practical, analytical, and methodological competencies. Students should be able to identify an ecological problem, formulate a research question, develop a hypothesis, determine appropriate research variables, select suitable methods of observation and sampling, collect reliable data, organize and analyze the obtained information, and formulate evidence-based conclusions.

Bioindicator-based investigations can support the development of each of these competencies. For instance, the observation of differences in lichen abundance between

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an industrialized area and a relatively less polluted area may lead students to formulate a hypothesis concerning the relationship between air quality and lichen distribution [Damayanti, Sueb & Rohman, 2021].

Subsequent field observations, standardized sampling, quantitative recording, comparison of results, and interpretation of ecological patterns enable students to experience the fundamental stages of scientific research in a context that is understandable and relevant to their everyday environment.

An important advantage of bioindicators in biology education is their accessibility. Many bioindicator organisms can be found in school surroundings, urban parks, gardens, forests, agricultural landscapes, ponds, streams, and other local ecosystems. This makes bioindicator-based research particularly suitable for school-level ecological investigations, where access to sophisticated laboratory equipment may be limited. Students can conduct meaningful observations using relatively simple materials and methods, including field notebooks, quadrats, transects, sampling containers, measuring instruments, photographic documentation, identification keys, and basic statistical procedures. Consequently, bioindication can contribute to the democratization of ecological research by demonstrating that scientific investigation does not necessarily require highly specialized laboratories and that scientifically valuable observations can be conducted within the local environment.

The use of bioindicators also contributes to the development of students' observational skills. Ecological research begins with the ability to recognize patterns and changes in the environment. Students who systematically observe organisms and their habitats learn to distinguish normal ecological variation from potentially significant environmental changes. For example, differences in plant vigor, leaf damage, species abundance, lichen coverage, algal composition, or the presence of sensitive aquatic organisms may provide initial evidence of environmental stress. Repeated observations over time allow students to identify temporal patterns and understand that ecosystems are dynamic systems influenced by both natural and anthropogenic factors. Thus, bioindicator-based activities can develop students' ability

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to perceive the environment as an interconnected biological system rather than as a collection of isolated organisms.

Another significant pedagogical potential of bioindicators is their contribution to the formation of students' analytical and comparative thinking. Ecological data rarely have meaning when considered in isolation. The abundance of a particular organism, for example, becomes more informative when it is compared across different sites, seasons, environmental conditions, or levels of anthropogenic disturbance. Students can therefore be encouraged to construct comparative tables, calculate relative abundance or frequency, determine species richness, and apply simple ecological indices where appropriate. Such activities provide an introduction to quantitative ecological analysis and demonstrate how biological observations can be transformed into measurable evidence. At the same time, students learn to recognize the limitations of biological indicators and understand that environmental conclusions should be based on multiple observations and complementary evidence rather than on a single indicator [Molefe, Aubin, 2021].

Bioindicator-based research is particularly valuable for understanding the relationship between biodiversity and ecosystem health. Biodiversity is not simply a measure of the number of species present in an ecosystem; it also reflects interactions among organisms and their responses to environmental conditions. Changes in species composition, community structure, dominance, or abundance may indicate ecological disturbance. By studying these characteristics, students can understand the ecological significance of biodiversity and recognize why the conservation of biological communities is essential for ecosystem stability and resilience. For example, a comparison of plant or invertebrate communities in relatively undisturbed and anthropogenically transformed habitats can demonstrate how environmental pressure may alter community structure. This approach provides a practical foundation for understanding ecological succession, ecological niches, tolerance ranges, competition, and ecosystem dynamics.

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The application of bioindicators also supports interdisciplinary learning. Ecological research naturally integrates concepts from biology, geography, chemistry, environmental science, mathematics, and information technology. Students may examine how chemical pollution influences organisms, map the spatial distribution of bioindicators, analyze temperature or soil characteristics, calculate ecological indices, and present their findings using digital tools. Such interdisciplinary activities correspond to contemporary approaches to STEM and inquiry-based education, in which students are expected to apply knowledge from different disciplines to solve authentic problems. Therefore, bioindicator-based ecological investigations can function as an effective educational platform for developing both subject-specific and transferable scientific competencies.

Field-based investigations using bioindicators can further contribute to the development of students' environmental awareness and ecological responsibility. Direct contact with natural ecosystems often creates a stronger understanding of environmental problems than abstract descriptions in textbooks. When students personally observe reduced biodiversity, environmental stress, habitat degradation, or changes in indicator organisms, ecological problems become concrete and meaningful.

This experience can encourage students to consider the consequences of human activities and to recognize the importance of sustainable resource use and biodiversity conservation. In this sense, bioindication has both an epistemological and an educational function: it helps students understand environmental processes while simultaneously fostering attitudes and behaviors associated with environmental responsibility [Persson, Andrée & Caiman, 2024].

The methodological organization of bioindicator-based activities is particularly important for ensuring their educational effectiveness. The teacher should not limit the activity to identifying indicator species or recording their presence. Instead, students should be involved in the complete research cycle. This may include defining the research problem, selecting an appropriate bioindicator, establishing sampling sites, determining observation criteria, collecting data according to standardized procedures,

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organizing the results, comparing ecological conditions, discussing possible sources of variation, and evaluating the reliability of the conclusions. Such organization transforms a conventional practical lesson into an authentic research experience. The teacher consequently assumes the role of facilitator and methodological guide, while students become active participants in the production and interpretation of scientific knowledge.

At the same time, the use of bioindicators in school research requires attention to methodological limitations. Biological responses are influenced by multiple environmental factors, and the presence or abundance of an indicator organism cannot always be attributed to a single source of environmental stress. Seasonal variation, habitat structure, microclimatic conditions, species interactions, soil properties, and natural ecological fluctuations may influence observed patterns. Therefore, students should be taught to distinguish correlation from causation and to consider alternative explanations for their findings. This aspect is pedagogically valuable because it develops critical thinking and scientific skepticism. Students learn that scientific conclusions should be supported by evidence, repeated observations, appropriate controls, and consideration of potential confounding variables.

The local environmental context provides additional opportunities for the effective implementation of bioindicator-based education. Urban ecosystems are particularly suitable for student investigations because they contain environmental gradients generated by traffic, industrial activity, construction, green spaces, recreational areas, and differences in land use. Such gradients can be used to investigate changes in plant communities, lichens, fungi, soil organisms, or other biological indicators. Similarly, freshwater ecosystems provide opportunities to study aquatic organisms in relation to water quality, while agricultural environments allow students to examine the effects of land management practices on biodiversity. The selection of locally relevant bioindicators can therefore increase students' motivation by connecting scientific research with environmental issues in their immediate surroundings.

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The development of ecological research skills through bioindicators is also consistent with the broader transformation of contemporary science education toward competency-based learning. Modern educational approaches increasingly emphasize not only what students know but also what they can do with their knowledge. Ecological competence includes the ability to understand ecological concepts, investigate environmental problems, evaluate evidence, communicate scientific findings, and make informed decisions. Bioindicator-based research provides an integrated context in which these competencies can be developed simultaneously. Students acquire factual knowledge about organisms and ecosystems while also learning how scientific evidence is generated, analyzed, communicated, and applied to environmental decision-making.

Furthermore, bioindicator investigations can promote collaborative learning. Ecological research frequently involves teamwork because field sampling, species identification, data recording, statistical analysis, and interpretation can be distributed among different members of a research group. Students working collaboratively learn to coordinate tasks, discuss methodological decisions, compare observations, resolve disagreements, and collectively formulate conclusions. Presentation of research results through posters, reports, oral presentations, or digital formats further develops scientific communication skills. Thus, the educational benefits of bioindicator use extend beyond ecological knowledge and include communication, cooperation, problem-solving, and research planning.

The integration of digital technologies can further enhance bioindicator-based ecological investigations. Students may use mobile applications for species identification, geographic information systems for mapping observations, spreadsheets for data organization, and statistical software for analyzing ecological patterns. Digital photography and georeferenced observations can facilitate long-term monitoring and comparison of environmental conditions. Such tools can increase the precision and attractiveness of ecological research while helping students acquire digital research competencies. Nevertheless, technology should function as a methodological support

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rather than replace direct ecological observation and biological interpretation.

From a pedagogical perspective, the use of bioindicators is therefore particularly significant because it connects three essential dimensions of biology education: scientific knowledge, practical research activity, and environmental responsibility. Students learn biological concepts through direct investigation of living organisms and simultaneously understand how these organisms can provide information about the condition of ecosystems. This creates a meaningful learning environment in which theoretical knowledge is continuously tested and reinforced through empirical evidence. The approach can also contribute to developing students' motivation toward biology by demonstrating the practical relevance of biological knowledge for solving contemporary environmental problems.

Despite the considerable potential of bioindicator-based approaches, their effectiveness depends on appropriate methodological design, teacher competence, selection of suitable indicator organisms, age-appropriate research tasks, and systematic evaluation of students' research outcomes. It is therefore important to investigate not merely whether bioindicators can be used in biology lessons, but how their purposeful integration influences the formation of specific ecological research skills. Particular attention should be paid to students' abilities to formulate research questions and hypotheses, conduct systematic observations, collect and process ecological data, analyze biodiversity patterns, interpret environmental relationships, evaluate evidence, and communicate scientifically justified conclusions.

Against this background, the use of bioindicators can be considered a promising methodological approach for strengthening ecological research competence in biology education. It provides students with accessible biological models for investigating environmental change and creates opportunities for authentic inquiry within both school and local ecosystems. The educational integration of bioindication can contribute to the transition from knowledge-centered instruction toward research-oriented and competency-based learning, while simultaneously supporting environmental awareness and responsible attitudes toward nature. Accordingly, the

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present study focuses on the pedagogical and methodological potential of bioindicators in the formation of students' ecological research skills, with particular emphasis on observation, hypothesis formation, field investigation, data collection, analysis, interpretation, and evidence-based scientific reasoning.

Main part. The formation of students' ecological research skills through the use of bioindicators can be considered an important direction in modern biology education because it creates a direct connection between theoretical ecological knowledge and practical investigation of the natural environment. Ecological concepts such as ecosystem stability, biodiversity, environmental pollution, anthropogenic impact, ecological tolerance, adaptation, and environmental quality are often presented to students at an abstract theoretical level. However, when these concepts are investigated through living organisms and their responses to environmental conditions, students are able to understand them more deeply and meaningfully. Bioindicators provide an appropriate methodological basis for such investigations because their distribution, abundance, physiological condition, or community structure may reflect changes in environmental conditions. Consequently, the classroom can be transformed from a place where ecological information is simply transmitted into an environment where students actively observe, investigate, compare, analyze, and interpret ecological phenomena.

The first stage in developing ecological research skills through bioindicators is the formation of students' ability to identify an environmental problem and formulate a research question. In traditional biology lessons, students frequently receive a predetermined problem and are expected to reproduce a known conclusion. In contrast, bioindicator-based investigations can begin with a real observation from the surrounding environment. For example, students may notice that certain organisms are abundant in one area but almost absent in another, that vegetation differs between locations, or that the composition of organisms in a polluted water body differs from that of a relatively clean water source. Such observations can stimulate scientific

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curiosity and encourage students to ask why these differences occur. The teacher can guide students toward transforming their observations into scientifically meaningful research questions, such as whether environmental pollution influences the abundance of particular organisms, whether biodiversity differs between anthropogenically transformed and relatively undisturbed habitats, or whether changes in habitat conditions are associated with changes in the structure of biological communities.

The formulation of hypotheses represents the next important component of ecological research competence. After identifying a problem, students should be encouraged to propose a scientifically testable explanation. For example, if students observe a lower diversity of lichens in areas characterized by intensive traffic, they may hypothesize that increased anthropogenic pressure is associated with a reduction in lichen diversity. Similarly, differences in aquatic macroinvertebrate communities may lead students to hypothesize that water quality influences the composition and abundance of aquatic organisms. The formulation of such hypotheses requires students to apply previously acquired biological knowledge and establish a logical relationship between an environmental factor and a biological response. In this process, the teacher's role is not to provide the correct answer but to help students construct hypotheses that can be investigated through observation and empirical evidence.

An essential characteristic of bioindicator-based ecological research is the selection of appropriate biological indicators. Students should understand that not every organism can function equally effectively as an indicator of a particular environmental condition. The suitability of an indicator depends on its ecological characteristics, sensitivity or tolerance to environmental changes, distribution, abundance, ecological specificity, and the possibility of reliable identification. Lichens, for example, have traditionally attracted considerable attention in studies of atmospheric environmental conditions because different species may exhibit different levels of tolerance to air pollution. Aquatic macroinvertebrates can provide information about freshwater ecosystem conditions because their community

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composition reflects differences in environmental quality and habitat characteristics. Plants can also serve as indicators of soil conditions, water availability, salinity, nutrient status, and anthropogenic disturbance. Soil organisms, including fungi and microorganisms, may provide information about changes in soil properties and ecological functioning. Through such examples, students learn that organisms are not merely objects of biological classification but can also serve as sources of ecological information.

Field investigation is one of the most important components of the formation of ecological research skills. Bioindicator research naturally encourages students to leave the purely theoretical classroom environment and conduct observations directly in ecosystems. During fieldwork, students can learn how to select observation sites, establish sampling areas, use transects or quadrats, record species presence and abundance, photograph organisms, describe habitat characteristics, and document environmental variables. Such activities develop practical research competence because students must follow a predefined methodology and maintain consistency between observations. The teacher can demonstrate the importance of standardized sampling by asking students to use similar sampling areas, observation periods, and recording procedures. In this way, students gradually understand that scientific reliability depends not only on what is observed but also on how the observation is conducted.

The use of comparative research designs significantly increases the educational potential of bioindicator studies. Students can compare two or more sites that differ in environmental characteristics, such as an urban center and a park, a roadside area and a less disturbed green space, an agricultural field and a natural ecosystem, or different sections of a freshwater system. By comparing biological indicators between these sites, students can identify patterns associated with environmental differences. Such comparisons encourage students to move from simple observation to analytical reasoning. They learn that the ecological significance of an organism's presence or absence becomes clearer when the observation is considered in relation to another site

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or reference condition. This approach also introduces students to the concept of control or reference sites, which is essential for interpreting ecological data.

The collection and organization of ecological data constitute another major component of the research process. Students should learn to record observations systematically rather than relying on memory or subjective impressions. Data may include the number of individuals, percentage coverage, species richness, frequency of occurrence, distribution patterns, or qualitative characteristics of organisms. Environmental parameters such as temperature, humidity, soil moisture, pH, water transparency, or habitat characteristics can also be recorded when appropriate. Students can organize their observations in field notebooks, tables, spreadsheets, or digital databases. This process contributes to the development of accuracy, discipline, and responsibility in scientific work. It also demonstrates that raw observations become scientifically useful only when they are recorded systematically and can subsequently be analyzed.

Quantitative analysis of bioindicator data provides an additional opportunity to develop students' mathematical and analytical competencies. Even at the school level, relatively simple calculations can be used to characterize ecological communities. Students can determine species richness, calculate relative abundance, compare frequencies, or examine differences between sampling sites. More advanced students may be introduced to diversity indices such as the Shannon–Wiener index or Simpson's index. The purpose of such calculations in educational settings is not merely to teach mathematical formulas but to demonstrate how numerical indicators can help describe complex biological communities. Students thereby understand that ecological research combines qualitative observations with quantitative evidence.

The interpretation of bioindicator data is perhaps the most intellectually demanding stage of the research process. Students must learn to explain observed ecological patterns rather than simply describe them. If one site contains greater species diversity than another, students should consider possible explanations related to habitat heterogeneity, pollution, disturbance, resource availability, microclimatic

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conditions, or other ecological factors. At the same time, students should understand that the observed relationship does not necessarily demonstrate a direct causal connection. This encourages them to consider alternative explanations and recognize the complexity of ecological systems. The development of this type of reasoning is particularly important because ecological phenomena are influenced by multiple interacting factors, and simplistic interpretations may lead to scientifically inaccurate conclusions.

Bioindicator-based research also contributes to the development of students' critical thinking. Students are encouraged to question the reliability of their observations, evaluate possible sources of error, and consider the limitations of their research design. For example, the absence of a particular indicator species from a sampling site does not necessarily mean that environmental conditions are unfavorable; the species may be naturally absent, overlooked during sampling, or affected by another ecological factor. Similarly, a high abundance of an organism cannot automatically be interpreted as evidence of good environmental quality. By discussing such methodological limitations, students learn that scientific knowledge is based on evidence that must be carefully evaluated. This process strengthens scientific skepticism and reduces the tendency to accept ecological explanations without sufficient evidence.

The role of the teacher is especially important in organizing these investigations. The teacher should provide methodological guidance while allowing students sufficient independence to make research decisions. At the beginning of the investigation, the teacher may introduce the concept of bioindication and demonstrate examples of indicator organisms. Subsequently, students can participate in selecting research questions, determining sampling sites, designing observation procedures, and interpreting results. Such a gradual transition from teacher-directed activity to student-directed investigation promotes scientific independence. The teacher becomes a facilitator who supports students in developing research competence rather than merely transmitting information.

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The educational effectiveness of bioindicator investigations can be increased through group-based research. Students can be divided into small research teams, with each team responsible for a particular sampling site or indicator group. One group may investigate vegetation, another lichens, another soil organisms, while another may analyze environmental parameters. After fieldwork, the groups can combine their results and develop a common interpretation. This approach promotes collaboration, communication, division of responsibilities, and collective problem-solving. It also reflects the organization of real scientific research, where environmental studies commonly involve specialists working together and integrating different types of evidence [Sejong, Jang, & Kim, 2024].

An important methodological advantage of bioindicator research is its potential to connect ecological education with local environmental problems. Students are more likely to demonstrate interest when research concerns an ecosystem that they encounter in their daily lives. Urban schools, for example, can investigate the ecological differences between heavily trafficked roads and nearby green areas. Schools located near agricultural land can investigate the effects of land use on plant and soil communities. Students living close to rivers, lakes, or reservoirs can investigate aquatic organisms and relate community composition to visible environmental conditions. Such locally oriented investigations make ecological education more relevant and can encourage students to recognize that environmental problems are not distant global phenomena but processes that may occur within their own communities.

The use of fungi and microorganisms as bioindicators can provide particularly valuable opportunities for advanced biology students. Although these organisms are less visible than plants or larger animals, their ecological functions and sensitivity to environmental conditions make them important components of ecosystem assessment. Students can investigate fungal diversity in different soils, compare fungal communities under different environmental conditions, or examine the relationship between fungal abundance and soil characteristics. Such research introduces students

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to the ecological significance of decomposers and microorganisms and demonstrates their contribution to nutrient cycling, organic matter decomposition, soil formation, and ecosystem functioning. At the same time, it can broaden students' understanding of biodiversity by demonstrating that ecological diversity extends beyond the organisms most commonly encountered in school biology lessons.

The integration of bioindicators into environmental education can also strengthen students' understanding of anthropogenic transformation. Human activities such as industrialization, urbanization, transportation, intensive agriculture, deforestation, waste accumulation, and excessive use of natural resources can modify ecosystem structure and functioning. Biological indicators can make these transformations observable through changes in species composition, abundance, distribution, or community structure. Students who investigate such changes can better understand the ecological consequences of human activity and the importance of environmental monitoring. This knowledge can subsequently be connected with broader concepts such as sustainable development, ecosystem resilience, biodiversity conservation, and environmental management.

Another important dimension is the development of students' scientific communication skills. Ecological research does not end with data collection and analysis; findings must be communicated clearly and logically. Students can prepare research reports, posters, presentations, tables, graphs, or digital maps based on their bioindicator investigations. They should be encouraged to explain the research problem, methodology, results, interpretation, and limitations of their work. Scientific communication activities help students distinguish between observation and interpretation and teach them to support conclusions with evidence. These skills are transferable beyond biology and are relevant to future academic, professional, and civic activities.

The integration of information and communication technologies can further strengthen bioindicator-based ecological research. Mobile devices can be used to photograph organisms, document sampling locations, and maintain digital records. Geographic

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information systems can help students visualize the spatial distribution of indicators, while spreadsheets and statistical programs can support quantitative analysis. Digital platforms can also facilitate the comparison of data collected by different student groups or schools. However, technological tools should be integrated in a pedagogically meaningful manner. The primary objective remains the development of ecological research thinking, while technology serves as an instrument for improving observation, organization, analysis, and presentation of evidence.

Bioindicator-based learning can also be organized as a long-term monitoring project rather than a single practical lesson. Repeated observations over several months or years allow students to investigate temporal changes in biological communities. Such monitoring can demonstrate seasonal variation, ecological succession, responses to environmental disturbance, or gradual changes associated with urban development and climate-related factors. Long-term projects are especially valuable for developing persistence and scientific responsibility because students learn that reliable ecological conclusions often require repeated observations over time. They also create opportunities for students from different academic years to contribute to the same research database, thereby establishing continuity in school-based ecological research. The assessment of students' ecological research skills should correspond to the stages of the research process. Assessment should therefore not be restricted to the correctness of the final answer. Students should also be evaluated according to their ability to formulate research questions, develop hypotheses, select suitable bioindicators, follow sampling procedures, record data accurately, analyze information, identify limitations, interpret results, and formulate evidence-based conclusions. Rubrics, research portfolios, observation protocols, field journals, presentations, and research reports can be used to assess these competencies. Such an approach provides a more comprehensive picture of students' scientific development and encourages them to view research as a process rather than simply a task with a predetermined answer.

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The formation of ecological research skills through bioindicators is also closely connected with environmental values. Scientific understanding and environmental responsibility can reinforce each other when students are directly involved in studying natural ecosystems. The experience of observing biodiversity, documenting environmental change, and analyzing the effects of anthropogenic activities can contribute to a stronger sense of responsibility toward the environment. Students may subsequently become more willing to participate in local environmental initiatives, biodiversity conservation activities, ecological monitoring, and sustainable resource-use practices. Thus, the educational role of bioindicators extends from the development of scientific competencies to the formation of environmentally responsible behavior.

Overall, the methodological potential of bioindicators lies in their ability to integrate observation, experimentation, fieldwork, quantitative analysis, critical thinking, and environmental awareness within a single educational framework. Their use allows students to investigate real ecological phenomena rather than merely memorize definitions and classifications. Through systematic bioindicator studies, students learn how scientific questions are transformed into research procedures, how observations are converted into data, how data are analyzed and interpreted, and how evidence can be used to support ecological conclusions. Such an approach contributes to the development of students who are not only knowledgeable in biology but are also capable of conducting independent ecological investigations and critically evaluating environmental information.

Therefore, the purposeful integration of bioindicator-based investigations into biology education can be regarded as an effective methodological mechanism for developing students' ecological research competencies. Its educational significance is particularly evident in the possibility of combining theoretical ecological knowledge with direct empirical investigation, encouraging students to explore local ecosystems, analyze biodiversity and environmental changes, and formulate scientifically justified conclusions. When appropriately designed and systematically implemented, bioindica-

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tor activities can transform ecological education into an active research-oriented process and create a foundation for the development of scientifically literate, environmentally responsible, and critically thinking learners.

Conclusion

The use of bioindicators in biology education represents an effective methodological approach for the formation and development of students' ecological research skills. The analysis presented in this study demonstrates that bioindicator-based activities provide favorable conditions for integrating theoretical ecological knowledge with practical research experience and for transforming students from passive recipients of information into active participants in the process of scientific inquiry. By investigating living organisms and biological communities as indicators of environmental conditions, students can acquire a deeper understanding of the relationships between organisms and their habitats, the effects of anthropogenic pressures, biodiversity changes, and the functioning and stability of ecosystems.

One of the most important educational outcomes of bioindicator-based research is the development of students' ability to conduct systematic scientific observations. Unlike conventional classroom activities based primarily on theoretical explanations, bioindicator investigations require students to observe real organisms, identify ecological differences, record biological characteristics, and compare environmental conditions. Such activities contribute to the development of accuracy, attentiveness, methodological discipline, and the ability to distinguish scientifically relevant observations from subjective impressions. Repeated field observations further strengthen students' understanding that ecological processes are dynamic and that reliable scientific conclusions require sufficient and appropriately collected evidence.

The application of bioindicators also creates favorable conditions for the development of students' ability to formulate research questions and hypotheses. Environmental differences observed in local ecosystems can serve as a starting point

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for scientific inquiry. Students learn to transform an initial observation into a research problem and subsequently develop hypotheses that can be tested through field or laboratory investigations. This process develops logical reasoning and strengthens students' understanding of the fundamental principles of scientific research. The ability to formulate and test hypotheses is particularly important because it represents a transition from reproductive learning to inquiry-based and research-oriented learning.

Another significant result is the development of students' practical research competencies. Through bioindicator investigations, students can learn how to select sampling sites, establish observation areas, apply standardized sampling procedures, record biological data, organize field information, and use appropriate tools for ecological assessment. These practical skills provide students with an authentic experience of the scientific research process. Moreover, the accessibility of many bioindicator organisms makes such investigations possible even in educational settings with limited laboratory resources. Schoolyards, parks, urban green areas, agricultural landscapes, ponds, streams, and other nearby habitats can serve as natural research laboratories.

Bioindicator-based education also contributes substantially to the development of students' analytical and quantitative competencies. The analysis of species richness, abundance, frequency, distribution, community composition, and biodiversity indices enables students to transform qualitative observations into measurable ecological evidence. The use of tables, graphs, spreadsheets, and, at more advanced levels, ecological diversity indices encourages students to interpret data systematically. This interdisciplinary dimension connects biology with mathematics, statistics, geography, information technology, and environmental science, thereby contributing to the development of broader scientific and digital competencies.

An important pedagogical outcome of bioindicator research is the development of students' critical thinking. Ecological systems are characterized by complex interactions, and biological responses are often influenced by several environmental

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factors simultaneously. Therefore, students must learn to avoid simplistic interpretations and consider alternative explanations for observed patterns. When students analyze why the abundance or diversity of an indicator organism differs between sites, they are encouraged to consider pollution, habitat structure, climatic conditions, soil properties, moisture, resource availability, and biological interactions. Such reasoning strengthens their ability to distinguish correlation from causation and to evaluate the reliability and limitations of ecological evidence.

The use of bioindicators is also valuable for developing students' understanding of biodiversity and ecosystem health. Changes in species richness, abundance, dominance, or community structure can provide an accessible way of demonstrating the consequences of environmental disturbance. Students can observe how anthropogenic transformation affects biological communities and how ecosystem characteristics differ under varying environmental conditions. Through these observations, abstract concepts such as ecological tolerance, environmental stress, ecosystem resilience, succession, biodiversity conservation, and ecosystem stability become more understandable and empirically meaningful.

The educational significance of bioindicator-based investigations extends beyond scientific knowledge and research skills. Direct participation in environmental research can strengthen students' ecological awareness and sense of environmental responsibility. When students personally observe changes in biodiversity, habitat degradation, pollution effects, or differences in biological communities, environmental problems become concrete rather than abstract. This experience can encourage environmentally responsible attitudes and motivate students to participate in biodiversity conservation, ecological monitoring, and local environmental protection activities. Consequently, bioindicator-based learning can simultaneously contribute to cognitive, practical, and value-oriented dimensions of environmental education.

The effectiveness of this approach, however, depends on appropriate methodological organization. The selection of bioindicators should correspond to the ecological characteristics of the study area, the educational objectives, students' age

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and cognitive level, and the available research resources. Students should also be taught that bioindicator observations have limitations and should preferably be interpreted together with other biological and, where possible, physicochemical measurements. Standardized sampling, repeated observations, appropriate controls or reference sites, accurate data recording, and critical interpretation are essential for improving the reliability of student research. Therefore, teachers require sufficient methodological preparation to guide students in conducting scientifically sound ecological investigations.

The teacher's role in this process should increasingly shift from the transmission of predetermined knowledge toward the facilitation of student inquiry. Effective implementation of bioindicator-based learning requires teachers to create research situations in which students can formulate questions, develop hypotheses, collect evidence, analyze results, and defend their conclusions. Collaborative research, project-based learning, fieldwork, laboratory investigations, and digital technologies can be integrated into this process to provide students with diverse opportunities for scientific activity. Such an educational model corresponds to contemporary competency-based approaches and supports the development of independent and scientifically literate learners.

In conclusion, bioindicators possess considerable methodological and pedagogical potential for the formation of students' ecological research skills. Their purposeful use enables students to acquire scientific knowledge through direct investigation of living systems, develop observation and analytical abilities, master basic research procedures, interpret ecological data, and formulate evidence-based conclusions. At the same time, bioindicator-based learning promotes biodiversity awareness, environmental responsibility, collaborative work, and critical scientific thinking. Therefore, the systematic integration of bioindicators into biology teaching can contribute significantly to the transition from predominantly knowledge-centered ecological education toward an inquiry-based, research-oriented, and competency-focused educational model.

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The broader significance of this approach lies in its ability to connect school-based scientific activity with real environmental challenges. By investigating biological indicators in their immediate surroundings, students can become active observers and researchers of their own ecosystems. This not only improves their understanding of biology and ecology but also prepares them to recognize, analyze, and respond responsibly to environmental problems. Consequently, bioindicator-based ecological education can be regarded as a promising methodological direction for preparing a generation of students capable of combining scientific knowledge with practical research skills and responsible environmental decision-making.

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INCLUSIVE EDUCATION

**THE ROLE OF ARTIFICIAL INTELLIGENCE IN FOSTERING INCLUSIVE EDUCATION:
A SYSTEMATIC LITERATURE REVIEW**

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Keywords: artificial intelligence, inclusive education, special educational needs, assistive technology, adaptive learning, Universal Design for Learning, educational equity

Abstract. Inclusive education, grounded in the principle that all learners - regardless of ability, background, or learning profile - should have equitable access to quality instruction, has become a central policy priority worldwide. Concurrently, artificial intelligence (AI) technologies are increasingly integrated into classrooms through adaptive learning platforms, intelligent tutoring systems, assistive communication tools, and automated assessment applications. This article presents a systematic review of empirical and theoretical literature examining the role of AI in advancing inclusive education. Following a structured search of major academic databases and a thematic synthesis of the retrieved studies, in line with PRISMA reporting principles, four principal domains of AI application are identified: (1) personalized and adaptive instruction, (2) assistive technologies for students with disabilities, (3) support for teachers through data-driven decision-making, and (4) inclusion of linguistically and culturally diverse learners. The review also highlights persistent challenges, including algorithmic bias, unequal access to digital infrastructure, insufficient teacher preparation, and data privacy concerns. Drawing on the Universal Design for Learning framework and existing typologies of AI in education, the article proposes policy and practice recommendations for the responsible integration of AI into inclusive educational systems. The findings suggest that while AI holds considerable promise for reducing barriers to learning, its benefits are contingent on deliberate, equity-oriented design and implementation.

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Introduction

Inclusive education has been enshrined as a global policy goal since the 1994 Salamanca Statement [11] and reaffirmed through Sustainable Development Goal 4, which calls for inclusive and equitable quality education for all learners [12]. In practice, however, education systems continue to struggle to accommodate the full diversity of student needs, including learners with disabilities, students from linguistic and cultural minorities, and those who require differentiated pacing or modality of instruction. Over the past decade, artificial intelligence (AI) has moved from a peripheral experimental technology to a mainstream feature of educational software, encompassing intelligent tutoring systems, speech and text recognition tools, automated captioning, adaptive assessment engines, and generative AI tutors.

The convergence of these two trends — the policy imperative of inclusion and the rapid diffusion of AI in classrooms — raises an important question: to what extent, and under what conditions, can AI technologies genuinely advance inclusive education rather than reproduce or deepen existing inequities? This article addresses that question through a systematic review of the academic literature published between approximately 2018 and 2025. The review is guided by three

research questions: (RQ1) What categories of AI application are reported in the literature as supporting inclusive education? (RQ2) What learning and participation outcomes are associated with these applications? (RQ3) What barriers and risks are identified that may limit or undermine the inclusive potential of AI?

Main part. Inclusive education is commonly understood not merely as the physical placement of students with diverse needs in mainstream classrooms, but as a systemic commitment to removing barriers to participation and achievement for all le-

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arners. The Universal Design for Learning (UDL) framework, developed by Meyer, Rose, and Gordon [8], offers a widely used pedagogical lens for this commitment. UDL proposes that curricula should provide multiple means of engagement, representation, and action/expression, so that variability among learners is treated as the norm rather than the exception. This framework is frequently invoked in the AI-in-education literature as a benchmark against which the inclusivity of a given technology can be assessed.

Ouyang and Jiao [9] propose a widely cited typology distinguishing three paradigms of AI in education: AI-directed learning, in which the system controls the pace and content and the learner is a recipient; AI-supported learning, in which the system scaffolds learner-centered activities while preserving learner agency; and AI-empowered learning, in which AI augments the learner's and teacher's own capabilities through collaborative, symbiotic interaction. This typology is useful for analyzing the literature on inclusive education, since different AI applications occupy different positions along this spectrum, with implications for learner autonomy and agency.

A growing body of scholarship cautions that AI systems can encode and amplify existing biases present in their training data, with disproportionate effects on already marginalized groups. Baker and Hawn [1] provide a comprehensive account of algorithmic bias in education, documenting how predictive and adaptive systems can systematically disadvantage students based on race, language background, or disability status. Fu and Weng [5] similarly call for human-centered, responsible AI practices in education, arguing that ethical safeguards must be embedded in the design process rather than added retrospectively. These concerns are directly relevant to

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inclusive education, where the populations most likely to benefit from AI support are often also those most vulnerable to algorithmic harm.

Following identification and screening of titles and abstracts, full texts of potentially eligible studies were assessed against the eligibility criteria. Included studies were analyzed using thematic synthesis, in which recurring concepts were coded and grouped into higher-order themes. This process yielded the four thematic domains presented in Section 4.1–4.4, together with a cross-cutting set of barriers presented in Section 4.5. As a review of secondary literature rather than a primary data-collection study, this article does not report new statistical findings; instead, it aims to consolidate and critically synthesize existing empirical evidence in order to inform theory, policy, and practice.

The most frequently reported application of AI in the reviewed literature concerns personalization: adaptive learning platforms and intelligent tutoring systems that adjust content difficulty, pacing, and feedback according to an individual learner's demonstrated performance. Ouyang and Jiao [9] note that such systems allow instruction to be differentiated at a scale that would be difficult for a single teacher to achieve unaided. For learners with attention difficulties, processing differences, or gaps in prior knowledge, adaptive sequencing has been reported to reduce frustration and support sustained engagement, though the reviewed studies caution that personalization algorithms trained predominantly on majority-population data may perform less reliably for atypical learning profiles.

A second major theme concerns AI-enabled assistive technologies designed explicitly for students with disabilities. Barua et al. [2] review a range of AI-enabled personalized assistive tools developed for children with neurodevelopmental disorders, including autism spectrum condition and attention-deficit/hyperactivity

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disorder, spanning speech-generating devices, emotion-recognition applications, and adaptive communication boards. Hopcan et al. [7] similarly document a systematic body of research on AI in special education, reporting applications in automatic speech recognition for students with speech and language impairments, real-time captioning for deaf and hard-of-hearing learners, and computer-vision-based tools supporting students with visual impairments. Chalkiadakis et al. [3] extend this discussion to the combination of AI with virtual reality, reporting that immersive, AI-adapted environments can support both academic accessibility and social inclusion for students with disabilities by allowing controlled, repeatable practice of real-world scenarios.

A third theme concerns the role of AI in supporting, rather than replacing, teachers. Garg and Sharma [6] report that AI-based tools can assist special-needs educators by automating routine assessment and documentation tasks, freeing time for direct instruction, and by providing data-driven insights into individual student progress that inform differentiated planning. Several reviewed studies emphasize that AI functions most effectively as a decision-support tool that augments professional judgment, rather than as a substitute for teacher expertise, particularly in contexts requiring nuanced understanding of a student's social, emotional, and behavioral needs. A fourth theme, somewhat distinct from disability-focused applications, concerns the use of AI to support students from linguistic and cultural minority backgrounds.

Salas-Pilco et al. [10] conduct a systematic review of AI and related technologies used to support minority students, identifying applications such as machine-translation-supported instruction, culturally responsive adaptive content, and AI-mediated communication that reduce language barriers between students, families,

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and schools. Fitas [4] similarly reports on AI applications that simultaneously address special-needs support and language-barrier reduction, arguing that these two dimensions of inclusion are often addressed by overlapping technological approaches, such as multimodal AI systems capable of translation, simplification, and adaptive scaffolding within a single platform.

Across the reviewed literature, four recurring barriers are identified. First, algorithmic bias: Baker and Hawn [1] document cases in which predictive models embedded in adaptive systems produced systematically less accurate or less favorable outputs for students from historically marginalized groups, underscoring the need for bias auditing prior to deployment. Second, unequal access to digital infrastructure: several studies note that the benefits of AI-enabled inclusion are contingent on reliable internet connectivity, appropriate devices, and technical support, which are unevenly distributed within and across countries, risking a widening rather than narrowing of educational gaps. Third, insufficient teacher preparation: multiple reviewed studies report that teachers frequently lack training in how to interpret AI-generated recommendations, evaluate their appropriateness for a given student, and integrate them into existing individualized education plans. Fourth, data privacy and consent: the collection of granular behavioral and, in some cases, biometric data from students with disabilities raises distinct ethical concerns regarding consent, data ownership, and the potential for stigmatizing profiling, a concern echoed by Fu and Weng [5] in their call for human-centered, responsible AI governance in educational settings.

Read together, the reviewed literature suggests that AI's contribution to inclusive education is best understood not as a uniform effect but as a set of distinct application types, each with different implications for learner agency and equity. Mapped onto the typology proposed by Ouyang and Jiao [9], assistive technologies for students with

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disabilities often function in an AI-supported or AI-empowered mode, augmenting the learner's own communicative or cognitive capacities while preserving agency; by contrast, some adaptive-sequencing systems risk functioning in a more AI-directed mode, in which the system's determination of a learner's pathway constrains rather than expands choice. This distinction matters for inclusive education specifically, because the UDL principle of providing multiple means of engagement and expression is more fully realized when learners retain meaningful agency over how they engage with adapted content, rather than being passively routed through it.

The discussion also highlights a tension between individualization and standardization. AI systems designed for scale often rely on data patterns drawn from majority populations, which can inadvertently disadvantage learners whose needs or response patterns diverge from those norms - precisely the learners that inclusive education aims to serve. Addressing this tension requires deliberate design choices, including diverse and representative training data, participatory design

involving students with disabilities and their families, and ongoing bias auditing, consistent with the responsible - AI principles articulated by Fu and Weng [5].

Conclusions

This systematic review indicates that artificial intelligence holds meaningful potential to advance inclusive education through personalized instruction, assistive technologies for students with disabilities, decision-support tools for teachers, and applications that reduce language and cultural barriers. At the same time, this potential is not automatic: it depends on deliberate, equity-oriented design, impleme-

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mentation, and governance. Based on the synthesized evidence, six recommendations are proposed for policymakers, school leaders, and developers:

- 1) embed Universal Design for Learning principles into the design and procurement of educational AI tools;
- 2) require bias auditing and disaggregated performance reporting for AI tools used in inclusive settings;
- 3) invest in structured professional development that equips teachers to critically interpret AI-generated recommendations;
- 4) address infrastructural inequities directly through investment in connectivity, devices, and technical support in under-resourced schools;
- 5) establish clear, context-appropriate data governance and consent frameworks for behavioral and biometric data from students with disabilities; and 6) support participatory design processes that involve students with disabilities, families, and special education professionals in the development and evaluation of AI tools intended for inclusive settings. Future research should prioritize longitudinal, mixed-methods studies that examine not only academic outcomes but also learner agency, social inclusion, and long-term equity effects of AI adoption in diverse educational systems, including comparative studies across countries with differing levels of digital infrastructure.

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