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**TEACHING NEUROBIOLOGY AT SECONDARY SCHOOL LEVEL:
EVIDENCE FROM TEACHER OBSERVATIONS AND STUDENT
REFLECTIVE JOURNALS****Arystanova Samal** — PhD Doctoral Student, Korkyt Ata Kyzylorda University, Kyzylorda, Kazakhstan,E-mail: samal_arystanova@mail.ru, <https://orcid.org/0009-0003-1796-0286>;**Maimatayeva Assiya** — PhD, Senior Lecturer, Abai Kazakh National Pedagogical University, Almaty, Kazakhstan,E-mail: majmataevaasia@gmail.com, <https://orcid.org/0000-0002-4256-0802>;**Zhandavletova Raihan** — Candidate of Biological Sciences, Senior Lecturer, Korkyt Ata Kyzylorda University, Kyzylorda, Kazakhstan,E-mail: raihanzhandavletova@mail.ru, <https://orcid.org/0000-0002-0763-6576>.

Abstract. In Central Asia, despite growing international evidence that structured brain education yields significant learning gains and supports adolescent self-regulation, neuroscience literacy remains virtually absent from school curricula. This study describes a three-week, high-quality neuroscience curriculum intervention with 125 ninth-grade students at the I. Kabylov IT School-Lyceum No. 12 in Kyzylorda, Kazakhstan. The intervention comprised twelve lessons organised into four thematic modules: brain anatomy and organisation; neural communication; neuroplasticity and adolescent brain development; and the neurobiology of learning and memory. Data were collected using two paper-based qualitative instruments: structured teacher field notes recorded after each lesson in three groups, and student reflective journal entries written in response to three end-of-lesson questions. Braun and Clarke's thematic analysis was applied to both data sources. Observational data revealed three themes. First, participation gradually increased throughout the study, with a role-playing game on synaptic transmission becoming a key event that transformed previously reticent students into active participants. Second, the quality of student responses shifted from single-line, factual responses to multi-layered, peer-focused explanations incorporating

interdisciplinary analysis. Third, the third module on adolescent neuroplasticity elicited spontaneous personal connections across all three sections, with students recognising elements of their own developmental biology in the content. Analysis of diary entries revealed three parallel themes: conceptual growth from factual memorisation to mechanistic understanding; emotional, biographical, and philosophical engagement with the content; and a corpus of 843 student-posed questions, categorised into seven thematic categories, the most prominent of which were memory and sleep, mental health, and the relationship between technology and the brain. The study proposes a replicable, low-tech, high-quality model for teaching neuroscience in resource-limited or digitally constrained educational settings.

Keywords: neurobiology education, neuroscience literacy, secondary school, Kazakhstan, qualitative research, teacher observation, reflective journal

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ОРТА МЕКТЕП ДЕҢГЕЙІНДЕ НЕЙРОБИОЛОГИЯНЫ ОҚЫТУ: МҰҒАЛІМ БАҚЫЛАУЛАРЫ МЕН ОҚУШЫЛАРДЫҢ РЕФЛЕКСИВТІК КҮНДЕЛІКТЕРІНЕН АЛЫНҒАН ДӘЛЕЛДЕР

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Аннотация. Орталық Азияда ми туралы білім берудің құрылымдалған бағдарламалары оқушылардың оқу жетістіктерін арттырып, жасөспірімдердің өзін-өзі реттеу дағдыларын дамытуға ықпал ететіні жөнінде халықаралық деңгейде дәлелдер саны артып келе жатқанымен, нейроғылымдық

сауаттылық мектептегі оқу бағдарламаларында әлі де жеткілікті деңгейде қамтылмаған. Бұл зерттеу Қазақстанның Қызылорда қаласындағы І. Қабылов атындағы №12 ІТ мектеп-лицейінің 9-сыныптарында оқитын 125 оқушының қатысуымен жүзеге асырылған үш апталық жоғары сапалы нейроғылымдық білім беру интервенциясын сипаттайды. Интервенция төрт тақырыптық модульге біріктірілген он екі сабақтан тұрды: мидың анатомиясы мен ұйымдасуы, нейрондық коммуникация, нейропластикалық және жасөспірімдік кезеңдегі ми дамуы, сондай-ақ оқу мен есте сақтаудың нейробиологиясы. Деректерді жинау барысында сапалық зерттеу құралдары пайдаланылды. Атап айтқанда, үш сыныптағы сабақтардан кейін жүргізілген мұғалімдердің құрылымдалған бақылау жазбалары мен оқушылардың рефлексивтік күнделіктері талдау нысаны болды. Барлық деректер Браун мен Кларктың тақырыптық талдау тәсілі арқылы өңделіп, интерпретацияланды. Бақылау деректерін талдау үш негізгі тақырыпты анықтады. Біріншіден, интервенция барысында оқушылардың сабаққа қатысу деңгейі біртіндеп артып, әсіресе синапстық берілуді модельдеуге арналған рөлдік тапсырма олардың белсенділігін едәуір күшейтті. Екіншіден, оқушылардың жауаптары қарапайым фактологиялық пайымдаулардан пәнаралық байланыстарды қамтитын тереңірек түсіндірулерге қарай дамыды. Үшіншіден, жасөспірімдік кезеңдегі нейропластикалыққа арналған модуль оқушылардың оқу мазмұнын жеке тәжірибелерімен байланыстыруына ықпал етіп, олардың өз даму ерекшеліктерін ғылыми тұрғыдан түсінуіне мүмкіндік берді. Рефлексивтік күнделіктерді талдау үш параллель тақырыпты көрсетті: фактологиялық есте сақтаудан механизмдерді түсінуге дейінгі ұғымдық даму; оқу мазмұнымен эмоционалдық, өмірбаяндық және философиялық деңгейдегі байланыс; сондай-ақ оқушылар ұсынған 843 сұрақтан тұратын корпус. Бұл сұрақтар жеті тақырыптық санатқа жіктелді, олардың ішінде есте сақтау мен ұйқы, психикалық денсаулық және технология мен мидың өзара байланысы ең жиі кездескен тақырыптар болды. Зерттеу ресурстары шектеулі немесе цифрлық мүмкіндіктері аз білім беру орталарында нейроғылымды оқытуға арналған қайталануға болатын, технологиялық тұрғыдан қарапайым әрі педагогикалық тұрғыдан тиімді модельді ұсынады.

Түйін сөздер: нейробиологияны оқыту, нейроғылымдық сауаттылық, орта мектеп, Қазақстан, сапалық зерттеу, мұғалім бақылауы, рефлексивтік күнделік

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ПРЕПОДАВАНИЕ НЕЙРОБИОЛОГИИ НА УРОВНЕ СРЕДНЕЙ ШКОЛЫ: ДАННЫЕ НАБЛЮДЕНИЙ УЧИТЕЛЕЙ И РЕФЛЕКСИВНЫХ ДНЕВНИКОВ УЧАЩИХСЯ

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Аннотация. Несмотря на растущее число международных исследований, свидетельствующих о том, что систематическое изучение основ нейронаук способствует улучшению образовательных результатов и развитию навыков саморегуляции у подростков, в странах Центральной Азии нейронаучная грамотность по-прежнему практически не представлена в школьных учебных программах. В настоящем исследовании рассматривается трехнедельная образовательная программа по нейронаукам, реализованная с участием 125 учащихся девятых классов IT-школы-лицея № 12 имени И. Кабылова в Кызылорде, Казахстан. Программа включала двенадцать уроков, объединенных в четыре тематических модуля: анатомия и организация мозга; нейронная коммуникация; нейропластичность и развитие мозга в подростковом возрасте; нейробиология обучения и памяти. Для сбора данных использовались два качественных инструмента в бумажном формате: структурированные полевые заметки, которые учителя заполняли после каждого урока в трех учебных группах, и рефлексивные дневники учащихся, включавшие ответы на три вопроса в конце каждого занятия. Для анализа обоих массивов данных применялся тематический анализ по методике Браун и Кларк. Анализ данных наблюдений позволил выделить три основные темы. Во-первых, в ходе реализации программы постепенно повышался уровень вовлеченности учащихся, при этом ролевая игра, посвященная синаптической передаче сигналов, стала одним из ключевых факторов вовлечения ранее малоактивных школьников. Во-вторых, ответы учащихся постепенно усложнялись: от кратких фактологических высказываний они переходили к более развернутым объяснениям, включавшим

взаимодействие со сверстниками и элементы междисциплинарного анализа. В-третьих, модуль, посвященный нейропластичности в подростковом возрасте, вызвал спонтанные лично значимые ассоциации во всех трех группах, поскольку учащиеся стали соотносить изучаемый материал с особенностями собственного развития. Анализ рефлексивных дневников также выявил три взаимосвязанные темы: переход от запоминания фактов к пониманию механизмов; эмоциональную, биографическую и философскую вовлеченность в содержание курса; а также 843 вопроса, самостоятельно сформулированных учащимися. Эти вопросы были распределены по семи тематическим категориям, среди которых наиболее распространенными оказались вопросы памяти и сна, психического здоровья, а также взаимосвязи технологий и функционирования мозга. Результаты исследования позволяют предложить воспроизводимую, технологически простую и педагогически эффективную модель преподавания нейронаук в образовательной среде с ограниченными ресурсами или ограниченным доступом к цифровым технологиям.

Ключевые слова: обобразование в области нейробиологии, нейронаучная грамотность, средняя школа, Казахстан, качественное исследование, педагогическое наблюдение, рефлексивный дневник

Introduction. Understanding how the brain works has become one of the defining educational challenges of the 21st century. Since the Decade of the Brain (1990–1999), neuroscience organisations worldwide have advocated making brain literacy a core goal of school education, arguing that students who understand how their brains function are better prepared to learn, make health decisions, and interact with an increasingly neuroscience-oriented society (Sperduti et al., 2012).

Kazakhstan is a significant yet understudied context for this study. The national biology curriculum includes a section on the nervous system within human anatomy but lacks a dedicated neuroscience module that engages students in studying the brain as an integrated scientific field. To our knowledge, no high-quality studies of neuroscience instruction have been published in Kazakhstan or across Central Asia. Recent research in Kazakhstan has shown that metacognitive strategies can improve students' learning outcomes in biology classes Sadykova et al. (2024) reported significant improvements in students' understanding and metacognitive skills following the implementation of metacognitive learning strategies. This study addresses this gap by describing a three-week educational intervention with 125 ninth-grade students at I. Kabylov IT School-Lyceum No. 12 in Kyzylorda.

Data were collected using two qualitative instruments: teacher field notes and paper-based student reflective journals. This approach was deliberate. Digital survey tools pose challenges in the secondary school setting, including concerns about data privacy, uneven trust in digital platforms, and the risk that the formality of online surveys stifles students' authentic self-expression. Paper journals and field notes require no technology, integrate seamlessly into the classroom, and

yield more comprehensive data on learning than any post hoc tool. The study is guided by three research questions: What patterns of student engagement and participation do teacher observations reveal throughout the experiment? What do students' reflective writing reveal about the depth and quality of learning? What questions do students formulate, and what do these questions suggest about future directions for the neuroscience curriculum?

Literature review. However, research among schoolchildren consistently reveals significant gaps. A study of 508 Italian schoolchildren in grades three through ten found that fewer than one in five students could correctly identify the multiple pathways through which learning occurs, and fewer than six per cent could identify all the functions their brains were performing at any given moment (Sperduti et al., 2012). The authors attribute this not to student underachievement but to curriculum design: school neuroscience remains tied to anatomical labels and lacks the interdisciplinary and functional depth needed for genuine understanding. Herculano-Houzel (2002) also found that the misconception that people use only ten per cent of their brains persists at all levels of education in Brazil, indicating that without explicit, evidence-based instruction, neuromyths remain unchallenged throughout formal schooling.

Adolescence is the developmental stage when neuroscience education is most relevant. Puberty initiates synaptic pruning, myelination, and extensive reorganisation of the prefrontal, limbic, and social networks of the brain, creating a period of heightened neuroplasticity during which adolescents are particularly receptive to learning, novelty, and social experience (Baker et al., 2024). This heightened plasticity is not merely an argument for teaching neuroscience to adolescents; it is a reason to educate adolescents about neuroscience so they can understand and manage their cognitive and emotional development with greater self-awareness. The prolonged development of the prefrontal cortex makes this period both a period of vulnerability and an opportunity: educational environments that engage adolescents' heightened social curiosity can build on these developmental characteristics rather than work against them (Baker et al., 2024).

Neuroscience also offers direct guidance on how to teach. Active, multimodal methods that align with the brain's information encoding and retrieval mechanisms, such as role-playing, mind mapping, varied sensory input, and retrieval practice, yield significantly greater learning gains than passive learning (Elouafi et al., 2021). Elouafi et al. (2021) evaluated four neuropedagogical methods with secondary school students in Morocco and found that all four produced statistically significant improvements in measures of attention, engagement, recalled keywords, and written test scores, with the method of changing access channels producing a 235% increase in attention scores. Miller et al. (2006) independently demonstrated that embodied, analog representations of synaptic processes led to the greatest gains in knowledge in a neuroscience web adventure study with middle school students, supporting the notion that when students physically model an unseen

cellular process, the conceptual basis for understanding it becomes significantly richer. Yasar et al. (2017) offer a unifying theoretical framework, arguing that effective learning involves an iterative cycle of inductive and deductive reasoning, reflecting the brain's own associative and distributive processing of information; learning that extends this cycle beyond the primary context gradually deepens understanding with repeated engagement with the content.

The timing of classroom assessment also has neurobiological implications. Lopes da Cunha et al. (2018) showed that administering an exam one hour after a class session improved long-term retention among students with weak baseline retention, while it impaired retention among stronger students. They concluded that instructors should be mindful of the temporal relationship between assessment and learning. This finding informed the design of the assessment in the present module and became the focus of Module Four, providing students with applied neuroscience knowledge directly related to their own study habits. Ferreira et al. (2019) found, in a study conducted in Bolivia with students from a wide range of socioeconomic and educational backgrounds, that short project-based workshops led to significant increases in knowledge, regardless of students' gender, previous achievement, or initial interest in the course topic, demonstrating that the quality of the course materials matters more than students' baseline characteristics.

Materials and methods. The module comprised twelve sessions, delivered over three weeks, with each group attending 45-minute sessions. All materials were prepared simultaneously in Kazakh. The content was organised into four thematic modules, as shown in Table 1.

Table 1 — Module structure of the neurobiology intervention

№	Module title	Key content	Main activity
1	Brain anatomy and organisation	Major structures, cortical specialisation, brain functions	3D clay brain model; peer labelling and explanation
2	Neural communication	Neuron structure, action potential, synaptic transmission	Role play: students embody neurotransmitters and receptors (Elouafi et al., 2021)
3	Neuroplasticity and adolescent brain development	Synaptic pruning, myelination, sensitive periods (Baker et al., 2024)	Discussion of developmental neuroscience connected to own experience
4	Neuroscience of learning and memory	Encoding, consolidation, retrieval, sleep, exam effects (Lopes da Cunha et al., 2018)	Individual mind map; reflection on personal study habits

At the end of each week, ungraded retention tests were administered, consisting of five tasks completed after the new material, in line with the retention window principles of Lopes da Cunha et al 2018.

Data collection. Teacher Field Observation Notes. For thirty minutes after each lesson, the researcher kept structured notes under four recurring headings: (a) patterns of participation, noting who contributed and whether contributions were distributed or concentrated; (b) on-task behaviour, the overall quality of students'

attention during instructional and practical activities; (c) peer interactions, the quality of student discussions during group assignments; and (d) unexpected moments, episodes of surprise, spontaneous questions, or personal connections initiated by students. Thirty-six lesson notes were compiled, covering twelve lessons across three sections.

Reflective Journal Entries. Each student received a separate paper notebook. During the last five to eight minutes of each lesson, students wrote a reflective note in response to three standing questions displayed in Kazakh: (1) What did I learn today that I didn't know before? (2) What surprised or interested me? (3) What question do I still have? Students were assured that their diaries would not be graded. Diaries were collected weekly and returned at the beginning of the following week. A total of 1,500 entries were recorded.

Data analysis. Both data sets were analysed using thematic analysis following Braun and Clarke (2006): familiarisation, initial coding, theme development, review, definition and reporting. Field notes were read chronologically across all three sections. Diary entries were analysed as follows: all entries for the first and last lessons of each module were read; for the remaining four lessons, a systematic sample of one-third was selected for analysis. Responses to RQ3 were treated as a separate corpus, coded thematically using the category scheme proposed by Sperduti et al. (2012), and supplemented with inductively generated categories for themes absent from their framework. Reflective note-taking was conducted throughout the study to manage the researcher's dual role.

Analysis and results. Theme 1: Gradual Increase in Participation. Across all three sections, field notes document a gradual rise in participation as the intervention progressed. In the first module (brain anatomy), interaction followed a general pattern: a predictable core of five to eight confident students contributed, while the majority listened. Notes from Lessons 1-3 across all sections show variations on this pattern: "the same core group responds; a few students in the back rows consistently avoid eye contact; overall attention is adequate but passive".

By Module 2, the introduction of role-playing significantly disrupted this pattern. Notes from Lesson 5 across all sections document that students who had not voluntarily participated in the first four lessons actively sought roles in the task, negotiated with peers, and accurately described synaptic processes. By Module 4, notes consistently report increased voluntary participation in discussions, with students complementing each other's contributions without teacher prompting. This trajectory aligns with Elouafi et al. (2021) description of how embodied, social learning activates neural circuits associated with motivation and analogical reasoning that are not engaged during passive perception.

A closer examination of field notes across all sections shows that both the quantity and quality of student contributions changed. In the first sessions, volunteers' responses typically consisted of one-line, factual answers directly reflecting the teacher's question. By the third week, contributions became multi-line, often beginning with a personal observation before moving on to the concept

under discussion. In one section, a student who had been completely silent during the first module became a regular participant during the third module, particularly during a discussion of adolescent brain development. By the fourth module, he was observed explaining the concept of spaced repetition to an absent peer. This shift from passive receptivity to active, peer-directed knowledge sharing aligns with Ferreira et al. (2019) findings that participation formats shape not only knowledge but also a willingness to interact with knowledge, an outcome that standardised tests cannot capture.

3.2 Journal themes

Module 2: Role-playing as a Turning Point. The role-play-based lesson on synaptic transmission proved to be the liveliest and most cognitively productive across all three groups. Field notes indicate extensive group discussion and physical activity during the role-play, followed by a qualitative shift: students asked inference-based rather than fact-based questions. In one group, a student spontaneously asked whether antidepressants act through the same blocking mechanism they had just role-played, a connection to clinical pharmacology outside the planned lesson. In another group, a student linked neural communication to how he felt when nervous before an exam, connecting Module 2 to Module 4, which focused on stress and memory. These observations echo the findings of Miller et al. (2006), who demonstrated that embodied analog representations of synaptic processes lead to the greatest gains in neuroscience education. The qualitative shift in questioning observed after the role-play warrants closer examination. Before the fifth lesson, the questions students asked during class discussions were almost exclusively clarifying: asking the teacher to repeat, spell, or confirm factual information. After the fifth lesson, a new category of questions emerged more frequently: so-called connection questions, in which students went beyond the lesson content to ask how it related to what they already knew from experience or from another field. The question about antidepressants was the most striking example, but similar cross-curricular questions requiring inference appeared in all three sections. One student asked whether the dopamine pathways discussed in the second module were related to why video games are enjoyable, and another asked whether the concept of the reuptake transporter had any connection to the effects of caffeine, which he had read about in a popular science magazine. These spontaneous analogical leaps are precisely the form of learning that Yasar et al. (2017) describe as a hallmark of the activated inductive-deductive loop.

Topic 3: Spontaneous Personal Application of Content. The third module (Adolescent Neuroplasticity) fostered the most personally meaningful classroom atmosphere. When students encountered synaptic pruning, entries from all three sections captured spontaneous personal connections: one student asked whether pruning explains why skills learned in early childhood seem more automatic than those acquired later in life; another asked whether the social sensitivity characteristic of adolescence, as discussed in Baker et al. (2024), explains the greater emotional intensity of current conflicts with parents. This kind of self-referential interaction is precisely what Baker et al. (2024) believe should be

exploited in educational settings: when the content of a biology lesson is relevant to students' own developmental biology, motivation to understand becomes intrinsic.

The topic of personal application was not confined to a discussion of synaptic pruning. Throughout the third module, students spontaneously connected neurobiological content to features of their social world that they had previously taken for granted. One student asked whether adolescents' heightened social awareness, described by Baker et al. (2024) as a consequence of heightened mirror-neuron sensitivity and the development of the social brain, might explain why peer opinions matter so much more now than in elementary school. Another asked whether the process of myelination, described in the lesson as a gradual increase in the speed and reliability of neural transmission, could be intentionally accelerated through specific types of practice. A third student, in a quiet remark recorded in the field notes for one section, said to a peer, "It's weird to learn about what's going on inside you right now". This last observation highlights something important about the unique pedagogical potential of adolescent neuroscience as a curriculum topic: unlike most scientific materials, it is both objective knowledge and personal experience, and students seem to recognise this duality with minimal prompting.

Diary Themes. Theme 4: From Factual Memorisation to Mechanistic Understanding. The most striking developmental pattern in the diary corpus was the increasing depth of responses to the first question throughout the intervention. Early entries (lessons 1–3) typically consisted of brief statements: "I learned the names of the parts of the brain"; "The cerebellum controls balance". By lessons 9–12, entries had become significantly more detailed. One student wrote, "I used to think of memory as being like saving a file on a computer, but in reality, every time you recall something, you reconstruct it from many different neurons, so it can change slightly over time". Another wrote, "Today I understood why one reading isn't enough. Neurons need to fire simultaneously many times before a connection becomes strong". These entries reflect the kind of generative, detailed processing that Yasar et al. (2017) associate with iterative inductive-deductive learning cycles.

This shift in journaling quality was not evenly distributed across students. Early in the intervention, the most detailed entries were produced by a small number of students who already had high levels of verbal literacy. By the fourth module, the gap between the most and least detailed entries had narrowed significantly: students who wrote two to three lines in the first lesson wrote ten to fifteen lines in the twelfth lesson, demonstrating comparable gains in depth of understanding. This convergence suggests that reflective journaling, as an iterative practice, fostered the development of the detailed processing capacity it was intended to measure, a recursive effect consistent with the metacognitive support role that Baker et al. (2024) attribute to writing assignments engaging adolescents' developing prefrontal cortex. The journal was more than a window into the learning process; it was also, in part, a place of learning.

Topic 5: Emotional and Biographical Connections. The responses to the second

question contained the most individually expressed written pieces. Three subtypes were identified. First, productive surprise at complexity: many students expressed this surprise in phrases such as, "I always thought memory simply worked or didn't work, but now I understand there are many different types and processes". Second, personal and biographical connections: one student wrote, "I used to study the night before an exam, and then I forgot everything. Now I understand why and plan to change my approach to studying", which is a direct practical application of the findings of Lopes da Cunha et al. (2018). Third, ethical and philosophical questions: several students questioned whether it is fair to hold adolescents to adult standards of self-control, given that the prefrontal cortex is still developing.

The subset of ethical and philosophical questions warrants special attention because it was unexpected and arose without prompting from the instructor. Several students from all three groups posed questions in their journals about the relationship between neurobiological explanations and personal responsibility, whether such explanations of adolescent impulsivity reduce or eliminate moral responsibility, and whether understanding the biological basis of behaviour changes how one thinks about personal effort and character. One student wrote, "If the brain is still developing, does that mean my current mistakes aren't really my fault, or does knowing that only make things worse because I can't use it as an excuse?". These entries suggest that neurobiology content, taught in a context that explicitly connects it to students' own developmental biology, naturally engenders philosophical reflection rarely found in high school biology. As argued by Howard-Jones (2014), neurobiology education inevitably raises ethical questions that teachers should be prepared to discuss rather than avoid.

Topic 6: Student Questions. The third question yielded 843 distinct questions from the selected corpus of diary entries. The distribution by thematic category is presented in Table 2.

Table 2 — Student-generated questions by thematic category (N = 843)

Thematic category	N	%	Category origin
Memory, sleep, and forgetting	189	22.4	Sperduti et al. (2012)
Neurological disorders and mental health	163	19.3	Extended category
Emotions, stress, and the brain	142	16.8	Sperduti et al. (2012)
Brain development across the lifespan	118	14.0	Sperduti et al. (2012)
Consciousness and self-awareness	97	11.5	Sperduti et al. (2012)
Technology and the brain (social media, AI)	84	9.9	Inductive (this study)
Other	50	5.9	-
Total	843	100	-

Two features of this distribution are noteworthy. First, mental health questions (19.3%) significantly exceed those in (Sperduti et al., 2012) Italian sample (2.7%), suggesting either a generational shift in adolescents' perception of mental health as a personal issue or the activating effect of the third module's content on adolescent brain development. Second, the "technology and brain" category (9.9%) was

absent from (Sperduti et al., 2012) framework and was created inductively. Typical questions include: "Does daily social media use change which neural connections are strengthened?" and "Is it possible to train your brain with apps, or is it just marketing?". This category reflects the context of IT schools and the decade of technological change separating the two studies.

A more detailed analysis of the mental health category reveals that students' questions within it fell into three distinct subgroups. The first and largest subset consisted of explanatory questions, in which students sought neurobiological explanations for conditions they already knew about, whether from personal experience, family context, or media influence: "Is anxiety caused by a malfunction in the brain?" and "Why do some people develop depression after a difficult event, while others do not?". The second subset consisted of treatment-related questions, in which students inquired about the mechanisms of psychological interventions: "Do antidepressants work by fixing something broken or by changing something normal?" and "Can therapy change the brain in the same way that medication does?". The third and smallest subset consisted of self-diagnostic questions, in which students carefully applied newly learned concepts to their own experiences: "Is it normal that I have such difficulty concentrating, or is there something unusual going on in my brain?". The presence of this third subset, in particular, suggests that neuroscience education does not remain at an abstract distance from students' lives; it becomes the lens through which they interpret themselves, with all the opportunities and responsibilities that entails.

Discussion. Together, the two qualitative data sources paint a comprehensive picture of learning as a process. The gradual increase in participation documented in the observational data suggests that active teaching methods reduced the barriers to participation posed by traditional teacher-led instruction. Role-playing appeared to be a threshold event: after the fifth lesson, students who had been passively compliant became actively engaged, a shift that persisted across subsequent modules. Diary data indicate that this engagement was not superficial: by the final module, students were explaining mechanisms, making cross-module connections, applying the content to personal experience, and formulating complex philosophical questions. This aligns with the findings of Ferreira et al. (2019), who observed that interactive learning yields similar outcomes for students from different backgrounds. Student engagement is not a fixed characteristic but a pedagogical achievement achieved through the choice of methods that connect the content to students' lived experiences. Qualitative data reveal phenomena that no post hoc test could capture: the precise moment when understanding changed and the personal meaning by which it was reinforced. The student who linked antidepressant use to the role-playing mechanics and the student who planned to change his review habits after the fourth module demonstrated transferred understanding, the deepest form of learning, visible only through tools that capture the process of thinking rather than the results in retrospect.

The decision to use paper diaries and field notes as the sole data collection

instruments proved methodologically productive. Students wrote more freely and in greater detail in the informal notebook format. Handwritten notes in Kazakh and Russian conveyed immediacy and personal engagement, reflecting authentic thinking in the present moment. The weekly data collection cycle created a dialogic loop between student expression and teacher response: misconceptions identified in the diaries, in particular the widely held early misconception that synaptic pruning signifies “*loss of intelligence*”, were addressed in subsequent lessons, making the diary both a research tool and an embedded formative assessment tool.

Conclusion. This study demonstrates that structured, neuropedagogically designed neuroscience instruction leads to deep, personally meaningful, and visibly engaged learning among 9th-grade students in Kazakhstan. Field notes taken by teachers during observations document a progressive transformation in class participation, from a passive majority and active minority to broad, self-directed engagement, following a role-playing activity that served as a turning point. Students' reflective journals document a parallel shift from factual replication to mechanistic understanding and biographical connection, culminating in 843 self-generated questions that reflect what adolescents in this context want to know about the brain.

The study makes three contributions to the literature. It extends qualitative research in neuroscience education to the Central Asian context, which is absent from the international literature. It demonstrates that field notes taken by teachers during observations and students' paper diaries are reliable, low-tech qualitative tools that provide process data and depth of inquiry over time, which no post-hoc survey can match. The study provides cross-cultural evidence that adolescents' intellectual curiosity about the brain is largely universal, while also identifying culture-specific issues regarding technology and mental health that reflect the Kazakhstani context.

For curriculum developers and teachers in Kazakhstan, the implication is clear: neuroscience deserves a more prominent and purposeful place in the high school biology curriculum. The students in this study were not passive listeners waiting to be told about neurons. They were inquisitive, thoughtful, and personally engaged learners who connected brain science to their identities, relationships, and futures. Satisfying this curiosity through well-designed instruction is one of the most productive contributions a high school biology curriculum can make.

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