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Modelling electromagnetic waves in Matlab as a tool for developing students' technical thinking

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Abstract. This article addresses the challenges of developing the technical thinking of higher education students through computational modelling of electromagnetic waves in the Matlab environment. Modern engineering requires specialists not only deep theoretical knowledge but also the ability to apply it in practice, particularly in electrodynamics, where abstract concepts benefit from visualization. The study analyses the role of computer modelling in the study of electrodynamics and its impact on the understanding of physical concepts. Two examples of modelling are presented: electromagnetic wave interference and propagation through different materials. For each example, a mathematical model, a description of the Matlab code, visualization of the results, and possible directions for extending the models for students' independent work are provided. The study proposes methods for numerical analysis, visualizing fields, and estimating the reflection and transmission coefficients of electromagnetic waves through various materials. The study demonstrates that modelling electromagnetic waves in Matlab contributes to a deeper understanding of the principles of their propagation, interaction, and superposition. Students can observe constructive and destructive interference, analyze electric and magnetic field behavior, and create dynamic animations. Modelling wave propagation through different materials allows for the analysis of wave interaction with multilayer structures, which is useful for understanding wave behavior and developing devices like filters or anti-reflective coatings. The obtained results confirm the effectiveness of using Matlab in the educational process, enhancing student motivation and developing practical skills. Prospects for further research include the integration of Matlab with machine learning libraries to predict wave process characteristics. This article is valuable for physics and engineering educators, as well as students interested in computational modelling of physical phenomena.

Key words: technical thinking, Matlab, electromagnetic waves, numerical modelling, electrodynamics, visualization of physical phenomena.

Моделювання електромагнітних хвиль у Matlab як інструмент розвитку технічного мислення студентів

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Анотація. У статті розглянуто актуальні проблеми розвитку технічного мислення здобувачів вищої освіти шляхом використання чисельного моделювання електромагнітних хвиль у середовищі Matlab. Сучасна інженерія вимагає від фахівців не лише глибоких теоретичних знань, але й уміння застосовувати їх на практиці, особливо в галузі електродинаміки, де абстрактні поняття потребують наочної візуалізації. В дослідженні проаналізовано роль комп'ютерного моделювання у вивченні електродинаміки та показано його вплив на засвоєння фізичних концепцій. Наведено два приклади моделювання: інтерференції електромагнітних хвиль та їхнього поширення через різні матеріали. Для кожного прикладу наводиться математична модель, опис програмного коду Matlab, візуалізація результатів, можливі напрямки розширення моделей для виконання самостійної роботи студентами. Запропоновано алгоритми реалізації чисельного аналізу, візуалізації полів та оцінки коефіцієнтів відбиття і пропускання електромагнітних хвиль крізь різні матеріали. Дослідження показує, що моделювання електромагнітних хвиль у Matlab сприяє глибшому розумінню принципів їх поширення, взаємодії та суперпозиції. Студенти можуть спостерігати зони конструктивної та деструктивної інтерференції, аналізувати поведінку електричного та магнітного полів, а також будувати динамічні анімації. Моделювання

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поширення електромагнітних хвиль через різні матеріали дозволяє аналізувати, як хвилі взаємодіють з багатшаровими структурами, що є корисним для розуміння поведінки хвиль у різних матеріалах та для розробки пристроїв, таких як фільтри або антивідбивні покриття. Отримані результати підтверджують ефективність використання Matlab в освітньому процесі, що сприяє підвищенню мотивації здобувачів вищої освіти, розвитку їхніх аналітичних навичок та формуванню практичних компетентностей. Перспективи подальших досліджень включають інтеграцію Matlab з бібліотеками машинного навчання для прогнозування характеристик хвильових процесів. Стаття може бути корисна викладачам фізики та інженерних дисциплін, а також студентам, які цікавляться комп'ютерним моделюванням фізичних явищ.

Ключові слова: технічне мислення, Matlab, електромагнітні хвилі, чисельне моделювання, електродинаміка, візуалізація фізичних явищ.

I Вступ

Розвиток технічного мислення є одним із ключових завдань підготовки здобувачів вищої освіти технічних спеціальностей. Сучасна наука та інженерія вимагають не лише володіння теоретичними знаннями, а й уміння застосовувати їх на практиці [1]. Особливо актуально це в контексті електродинаміки, де вивчення таких понять як електричні та магнітні поля, їхні взаємозв'язки та вплив на матеріальні об'єкти, складно сприймаються без наочних демонстрацій.

Електродинаміка також має практичне значення в інженерії, зокрема в розробці сучасних електронних пристроїв, систем передачі даних і засобів зв'язку. Удосконалення методів аналізу електромагнітних явищ сприяє створенню більш ефективних і екологічних технологій, що відповідають запитам сучасного суспільства.

Одним із ефективних методів розвитку технічного мислення є комп'ютерне моделювання, що дозволяє візуалізувати фізичні явища, досліджувати їхню поведінку в різних умовах та аналізувати результати. Останнім часом для вирішення різноманітних завдань активно використовуються програми комп'ютерної математики, такі як Excel, Mathcad, Scilab, Maple, LabVIEW, AutoCad [2-6] тощо. Раніше нами висвітлювалося використання деяких із зазначених програм у процесі навчання фізики й математики у закладах вищої освіти [7-9]. Використання таких математичних пакетів дає змогу розв'язувати різноманітні прикладні задачі, варіювати параметри в широких межах та краще розуміти досліджувані явища й процеси.

Одним із популярних інструментів для чисельного аналізу, зокрема для моделювання електромагнітних хвиль, є спеціалізоване програмне забезпечення Matlab. Цей набір інструментів здобув визнання у багатьох країнах, ставши стандартним засобом для оформлення інженерної документації та підготовки наукових матеріалів [10]. У свій навчальний процес дану систему впровадили такі заклади освіти як факультет фізики та астрономії Сієнського коледжу, геологічний факультет William & Mary, фізичний факультет Університету Св. Томаса. Завдяки гнучкості цього середовища, здобувачі освіти можуть реалізовувати складні математичні моделі, використовуючи метод кінцевих різниць у часовій області (FDTD) та інші чисельні методи [11]. Matlab дозволяє не лише виконувати аналітичні розрахунки, а й візуалізувати електромагнітні поля, моделювати поширення хвиль та аналізувати взаємодію полів із матеріальними об'єктами.

Загальна методика застосування комп'ютерів в освітньому процесі фізики викладена в роботах вітчизняних вчених П. С. Атаманчука, В. Ф. Заболотного, О. І. Іваницького, Ю. А. Пасічника, Н. В. Стучинської. Застосування Matlab на заняттях фізики розглядається в роботах Бобрицької Г. С. [17], Гаєва Є. О. [18], Поведи Р. А. [19] та інших. Світові практики [12-16] демонструють, що впровадження Matlab у навчання сприяє розвитку мислення, концепцій і навичок, а також є джерелом мотивації здобувачів освіти до вивчення фізико-математичних дисциплін. Наявні дослідження підтверджують, що робота з програмними пакетами для моделювання позитивно впливає на здатність здобувачів освіти розв'язувати складні технічні задачі та розуміти фізичну сутність явищ. Однак питання використання Matlab під час вивчення фізики залишається відкритим, адже розвиток комп'ютерних технологій та їх застосування в освітньому процесі відбувається динамічно, що вимагає постійного оновлення методичних підходів, удосконалення навчальних матеріалів та адаптації до сучасних освітніх стандартів.

Метою дослідження є розробка методичного підходу до застосування програмного пакету Matlab під час моделювання електромагнітних хвиль у загальному курсі фізики, а також аналіз його впливу на засвоєння навчального матеріалу та розвиток технічного мислення здобувачів вищої освіти.

Для досягнення поставленої мети було розв'язано наступні завдання:

– сформульовано алгоритм розв'язування фізичних задач на прикладі двох моделей: 1) візуалізація інтерференції електричних і магнітних хвиль; 2) дослідження поширення електромагнітних хвиль в різних середовищах;

– досліджено вплив використання Matlab на ефективність засвоєння фізичних концепцій та розвиток технічного мислення здобувачів освіти через алгоритмічні та чисельні методи моделювання.

У статті розглянуто переваги використання моделювання, наведені приклади практичних задач та обговорюється вплив візуалізації на розуміння ключових концепцій і розвиток креативних підходів до вирішення інженерних проблем.

II Матеріал і методи дослідження

У психології наразі відсутнє чітке визначення технічного мислення, його іноді прирівнюють до практичного чи образного мислення. Також вважається, що технічне мислення є частиною практичного, оскільки останнє формується в процесі практичної діяльності [20]. Воно поєднує логічне, просторове, алгоритмічне та системне мислення, що є критично важливим для майбутніх інженерів.

Технічне мислення розвивається в процесі аналізу складних задач, проектування моделей, розрахунків і перевірки результатів. Matlab, як універсальне середовище для моделювання, дозволяє створювати візуальні моделі електромагнітних хвиль, що значно полегшує розуміння фізичних явищ.

Під час роботи з Matlab студенти засвоюють такі важливі аспекти технічного мислення, як аналіз і синтез, просторове уявлення, пошук оптимальних рішень, тощо. Освітній процес, побудований на застосуванні Matlab, стимулює розвиток не лише технічного, але й аналітичного та креативного мислення, оскільки вимагає нестандартних підходів до розв'язання задач, а сам процес моделювання електромагнітних хвиль у Matlab включає декілька важливих етапів (рис. 1).

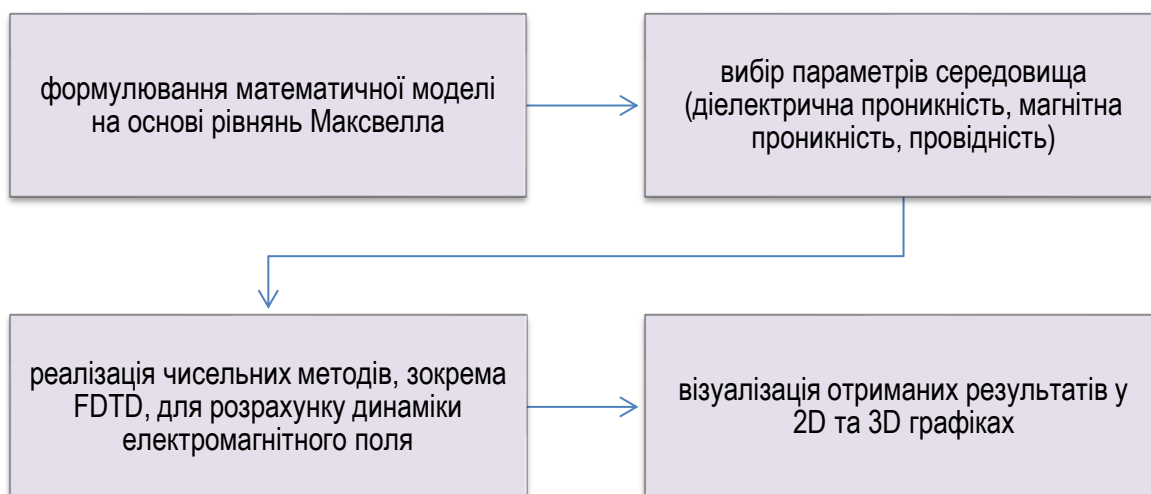


Рис. 1. Етапи процесу моделювання електромагнітних хвиль у Matlab

Застосування Matlab як засобу для моделювання електромагнітних хвиль позитивно впливає на розвиток технічного мислення студентів, сприяючи інтеграції теоретичних знань із практичними навичками. До основних ефектів які можна спостерігати при провадженні системи Matlab в освітній процес можна віднести:

- формування системного підходу до аналізу фізичних явищ;
- підвищення мотивації здобувачів освіти завдяки практичній спрямованості завдань;
- набуття практичних навичок використання математичного пакету Matlab в подальшій професійній діяльності;
- розвиток технічного мислення під час проведення комп'ютерних фізичних експериментів.

Розглянемо алгоритм застосування системи Matlab для моделювання електромагнітних хвиль на прикладі двох моделей.

III Результати

Приклад 1. Демонстрація інтерференції електромагнітних хвиль

Візуалізація інтерференції електричних і магнітних хвиль у Matlab може бути реалізована через побудову графіків, які показують результати суперпозиції хвиль у просторі та часі. Для електромагнітних хвиль можна візуалізувати взаємопов'язані осциляції електричного поля E і магнітного поля B .

Ось основні кроки для побудови математичної моделі демонстрації інтерференції електромагнітних хвиль:

1. Рівняння електромагнітної хвилі.

Електромагнітна хвиля у вільному просторі описується рівняннями [4]:

$$\begin{aligned} \vec{E}(z, t) &= E_0 \cos(\vec{k}z - \omega t) \hat{x}, \\ \vec{B}(z, t) &= B_0 \cos(\vec{k}z - \omega t) \hat{y}, \end{aligned} \quad (1)$$

де E_0 – амплітуда електричного поля; B_0 – амплітуда магнітного поля,

$$B_0 = E_0/c;$$

c – швидкість світла; z – координата в просторі; t – час; k – хвильове число,

$$k = 2\pi/\lambda;$$

ω – кутова частота,

$$\omega = 2\pi f.$$

2. Інтерференція хвиль.

Інтерференція виникає, якщо є дві або більше хвиль із різними фазами, частотами або напрямками поширення. Наприклад маємо дві хвилі з різними фазами:

$$\vec{E}(z, t) = E_1 \cos(\vec{k}z - \omega t) + E_2 \cos(\vec{k}z - \omega t + \varphi), \quad (2)$$

де φ – різниця фаз.

Цей принцип будемо реалізовувати в програмному коді.

3. Matlab-код для візуалізації.

Код для візуалізації інтерференції представлено на рис. 2.

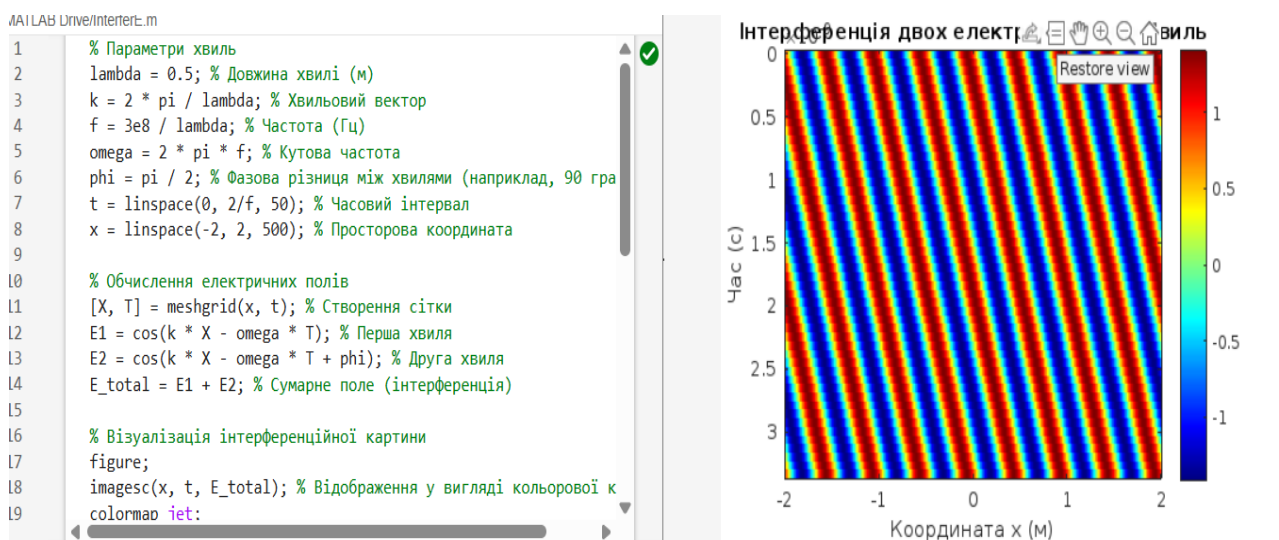


Рис. 2. Візуалізація інтерференції електромагнітної хвилі у двовимірному просторі

4. Результати роботи програми.

Що побачимо на графіках?

- інтерференційну картину (рис. 2);
- графік електричного поля, який відображає зміну результуючого поля в просторі та часі: видно зони конструктивної та деструктивної інтерференції (рис. 3);
- графік магнітного поля – за аналогією, як для електричного поля (рис. 3).

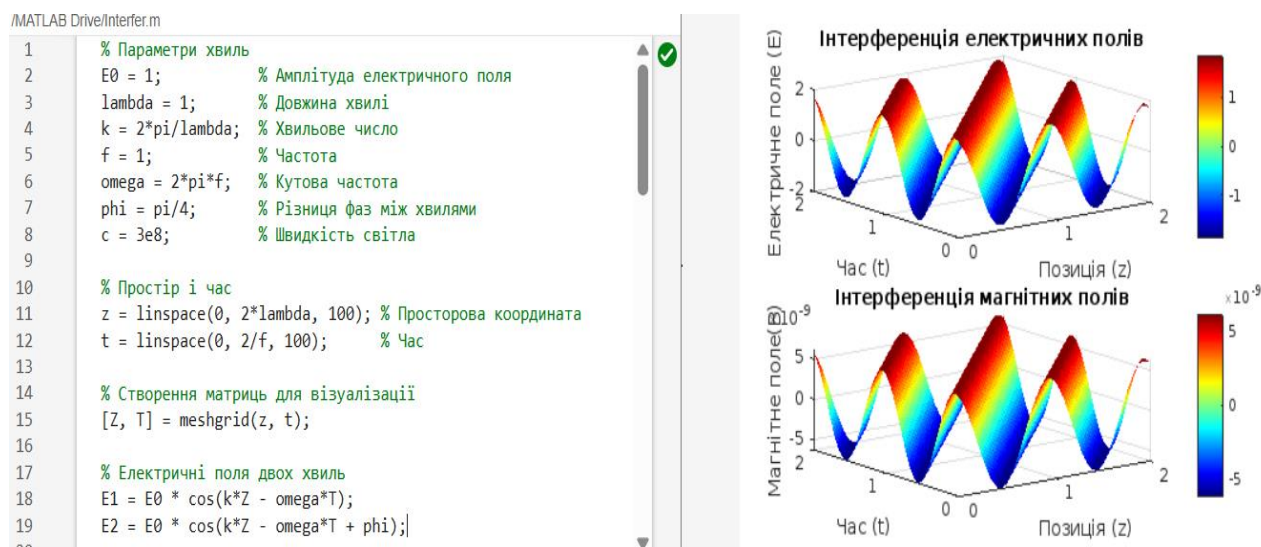


Рис. 3. Візуалізація інтерференції електромагнітної хвилі у тривимірному просторі

Можливі напрямки розширення програми які можна запропонувати для самостійної роботи здобувачів освіти з метою розвитку технічного мислення:

1. Додайте більше хвиль із різними фазами, амплітудами або напрямками поширення.
2. Додайте анімацію: зафіксуйте z і оновлюйте t .
3. Побудуйте векторне поле для електричного та магнітного компонентів у просторі.

На рис. 4. можна побачити результати розширення програми для моделювання та візуалізації інтерференції електромагнітної хвилі розробленої здобувачами вищої освіти в межах виконання завдання.

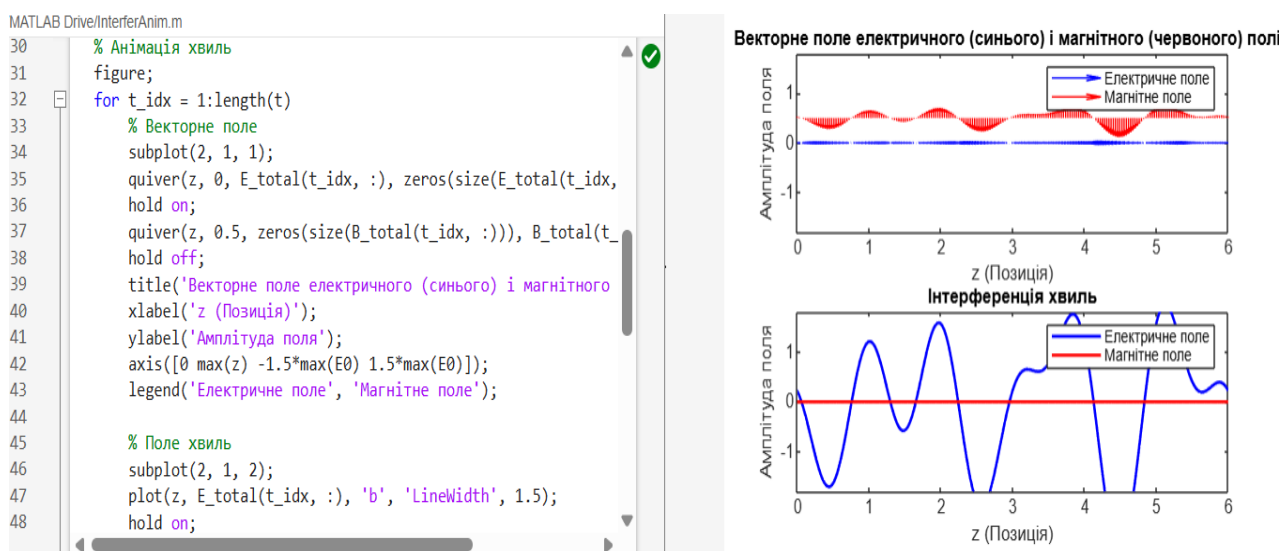


Рис. 4. Анімація інтерференції електромагнітної хвилі

Основні аспекти коду охоплюють відповідні завдання, а саме додано кілька хвиль із різними фазами, амплітудами та напрямками поширення, додано анімацію, яка оновлює хвилі з часом, побудовано векторне поле для електричного та магнітного компонентів у просторі.

Що видно під час виконання програми:

1. Векторне поле електричних і магнітних полів у просторі.
2. Графік суперпозиції хвиль із зображенням конструктивної та деструктивної інтерференції.
3. Динамічну анімацію хвиль у просторі та часі.

Таким чином візуалізація інтерференції електромагнітних хвиль у Matlab дозволяє глибше зрозуміти принципи їх поширення, взаємодії та суперпозиції. Реалізація коду допомагає студентам спостерігати зони конструктивної та деструктивної інтерференції, аналізувати поведінку електричного та магнітного полів, а також будувати динамічні анімації. Подальше розширення програми – додання додаткових хвиль, зміна параметрів та візуалізація векторних полів – сприяє розвитку технічного мислення та закріпленню теоретичних знань на практиці.

Приклад 2. Демонстрація поширення електромагнітних хвиль через різні матеріали

Моделювання поширення електромагнітних хвиль через різні матеріали є важливим аспектом вивчення електромагнетизму та оптики. Matlab надає потужні інструменти для чисельного моделювання таких процесів [22]. Розглянемо основні етапи побудови математичної моделі для дослідження поширення електромагнітних хвиль у різних матеріалах.

1. Вибір основних параметрів, що впливають на поширення електромагнітних хвиль.

Щоб точно змоделювати передачу електромагнітних хвиль, необхідно визначити властивості матеріалу, через який проходять хвилі. Основними характеристиками матеріалу є:

– діелектрична проникність ϵ (визначає вплив середовища на електричну компоненту електромагнітної хвилі);

– магнітна проникність μ (впливає на магнітну складову електромагнітної хвилі).

Сукупність цих властивостей визначає швидкість світла в матеріалі, яка може відрізнятися від швидкості у вакуумі ($c \approx 3 \cdot 10^8$ с). У більшості діелектричних матеріалів значення ϵ та μ перевищують їхні вакуумні значення, що зменшує швидкість поширення хвилі.

Далі визначимо властивості падаючої електромагнітної хвилі:

– частота f (кількість коливань за секунду, зазвичай вимірюється в Гц);

– довжина хвилі λ (просторова протяжність одного повного циклу хвилі, часто вимірюється в метрах);

– амплітуда A (максимальна величина електричного та магнітного полів хвилі);

– поляризація (орієнтація вектора електричного поля відносно напрямку поширення хвилі).

2. Розробка програмного коду для побудови комп'ютерної моделі поширення електромагнітних хвиль в різних середовищах.

Коли електромагнітна хвиля стикається з межею розділу між двома матеріалами з різними властивостями, частина хвилі відбивається назад у перший матеріал, а частина передається в другий матеріал. Коефіцієнти відбиття (R) і коефіцієнти пропускання (T) описують відношення амплітуд відбитого і пропущеного світла до амплітуди падіння відповідно.

Нижче представлено приклад реалізації програми (рис. 5), яка моделює поширення електромагнітної хвилі через багат шарову структуру з різними діелектричними проникностями [4].

У результаті реалізації програми ми отримуємо модель яка дозволяє:

– будувати графік залежності електричного поля від позиції у просторі;

– візуалізувати графіки для відображення падаючої, відбитої та пропущеної хвилі;

– візуалізацію поля в просторі від -5 см до 5 см;

– розрахувати поле для хвиль у всіх трьох областях: перед структурою, всередині та після неї;

– обчислити коефіцієнти відбиття і пропускання та показати, як виглядає хвиля при проходженні через багат шарову структуру.

Дана програма дозволяє аналізувати взаємодію електромагнітної хвилі з багат шаровими структурами, що є корисним для розуміння поведінки хвиль у різних матеріалах та для розробки пристроїв, таких як фільтри або антивідбивні покриття.

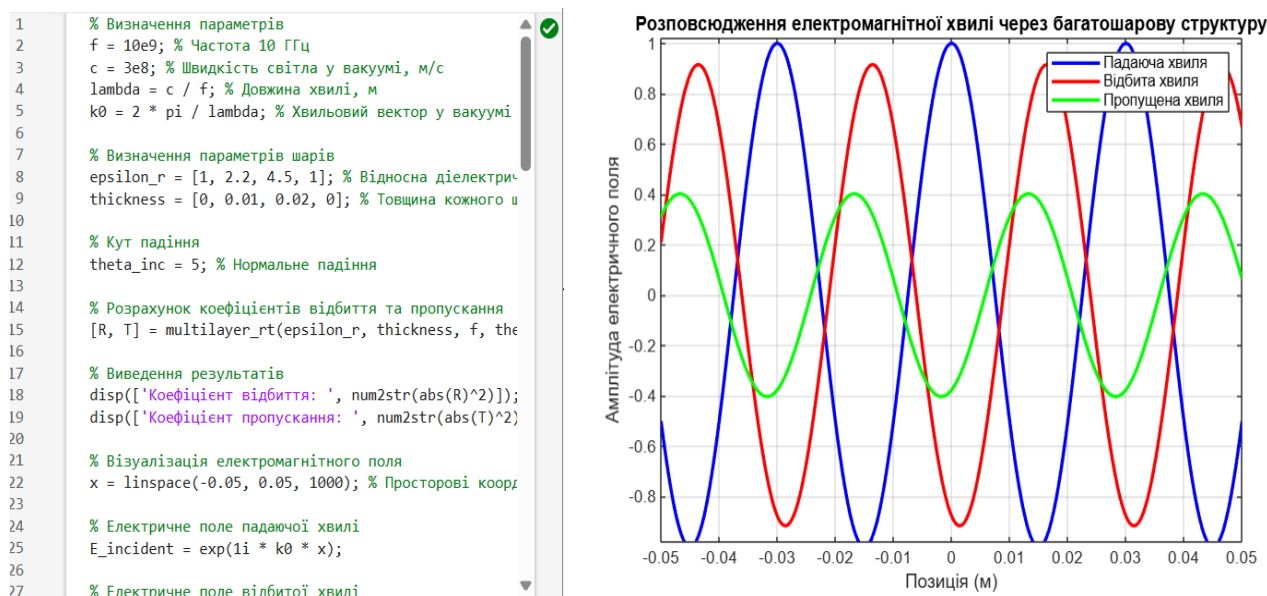


Рис. 5. Моделювання поширення електромагнітних хвиль через різні матеріали

Для розвитку технічного мислення можна запропонувати налаштувати модель для вирішення конкретних сценаріїв або запитань. Наприклад, можна попросити здобувачів освіти:

1. Дослідити вплив зміни частоти або поляризації падаючої хвилі.
2. Проаналізувати поведінку хвиль під різними кутами падіння.
3. Дослідити вплив кількох поверхонь матеріалів.
4. Обчисліть потужність, яку передає або відбиває поверхня.

Всі ці задачі здобувач освіти може виконати, додаючи зміни в код програми і провівши дослідження поставлених питань. На рис. 6 наведено результат роботи програми, розробленої здобувачами вищої освіти під час виконання завдання на дослідження процесу відбивання світла при зміні частоти падаючого світла.

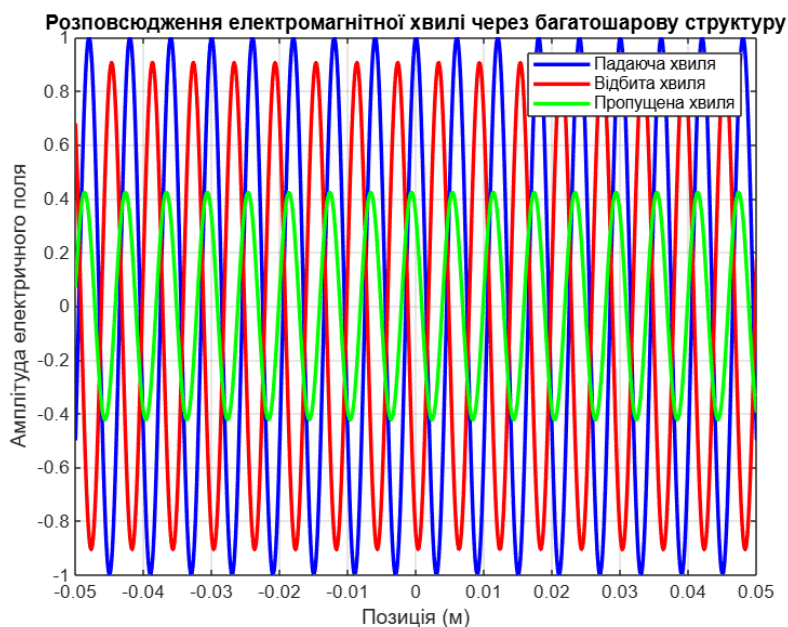


Рис. 6. Моделювання поширення електромагнітних хвиль через різні матеріали.
Зміна частоти падаючого світла

IV Обговорення

Досвід інтеграції Matlab у курс фізики показав підвищення зацікавленості здобувачів освіти матеріалом, який вивчається, а також покращення розуміння здобувачами освіти фундаментальних концепцій. Завдяки цьому інструменту студенти можуть не лише теоретично засвоювати матеріал, а й на практиці досліджувати поведінку хвиль у різних середовищах.

Використання Matlab в освітньому процесі має багато переваг, серед яких розвиток алгоритмічного мислення та навичок програмування, засвоєння абстрактних концепцій через наочну візуалізацію, формування технічного мислення через самостійно виконане моделювання фізичних явищ.

Водночас існують певні обмеження використання Matlab у процесі викладання фізики здобувачам вищої освіти технічних спеціальностей, як от необхідність базової підготовки студентів у програмуванні, витрати часу на оптимізацію обчислювальних алгоритмів для складних симуляцій.

Перспективи подальших досліджень включають інтеграцію Matlab із бібліотеками машинного навчання для прогнозування характеристик хвильових процесів.

Результати проведеного дослідження демонструють високу ефективність використання Matlab для моделювання електромагнітних хвиль у навчальному процесі. Візуалізація складних електромагнітних явищ, таких як інтерференція та поширення хвиль через різні матеріали, сприяє глибокому розумінню фундаментальних концепцій та розвитку технічного мислення студентів.

Порівнюючи отримані результати з даними, представленими в літературі, можна відзначити, що використання Matlab у навчанні електромагнетизму відповідає сучасним тенденціям інтеграції інформаційних технологій у вищу освіту. Зокрема, результати корелюють з дослідженнями, які підкреслюють позитивний вплив комп'ютерного моделювання на розвиток інженерних компетенцій студентів [2, 5, 11].

Метод кінцевих різниць у часовій області (FDTD), використаний у моделюванні, є одним із найбільш ефективних чисельних методів для моделювання електромагнітних хвиль, що підтверджується його широким застосуванням у навчальному процесі [12].

Досвід інтеграції Matlab у курси електромагнетизму, описаний у статті, підтверджує висновки інших дослідників про підвищення зацікавленості студентів та покращення розуміння фундаментальних концепцій [15, 16].

Отримані результати підтверджують гіпотезу про те, що моделювання електромагнітних хвиль у Matlab є ефективним інструментом для розвитку технічного мислення студентів. Використання Matlab дозволяє студентам не лише теоретично засвоювати матеріал, але й на практиці досліджувати поведінку хвиль у різних середовищах, що сприяє формуванню системного підходу до аналізу фізичних явищ та розвитку практичних навичок.

Враховуючи обмеження, пов'язані з необхідністю базової підготовки студентів у програмуванні та витратами часу на оптимізацію обчислювальних алгоритмів, можна стверджувати, що інтеграція Matlab у навчальний процес вимагає ретельного планування та методичної підтримки.

V Висновки

Моделювання поширення електромагнітних хвиль за допомогою Matlab є ефективним інструментом для вивчення фізичних явищ. Реалізовані математичні моделі дозволяють аналізувати процеси відбиття, пропускання та поширення хвиль у багатосарових структурах, що має важливе значення для розробки оптичних і радіотехнічних пристроїв.

Отримані результати демонструють, що використання чисельного моделювання в освітньому процесі сприяє не лише кращому розумінню теоретичних аспектів електродинаміки, а й розвитку технічного мислення здобувачів освіти. Завдяки можливості налаштування параметрів моделі студенти можуть самостійно досліджувати вплив частоти, кута падіння та структури середовища на поведінку хвиль, що розвиває їхні аналітичні та дослідницькі навички.

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The Indispensable Imperative: Navigating the Evolving Landscape of Teaching Engineering Ethics in a Dynamic Societal Context

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Abstract. In an era of rapid technological advancement and escalating societal expectations, the effective teaching of engineering ethics has become an indispensable imperative. While traditional pedagogy successfully imparts foundational ethical principles and codes of conduct, a significant body of literature suggests a critical chasm between this theoretical knowledge and the complex, high-pressure realities of professional practice. This study addresses this existing gap between the abstract ethical principles taught in engineering curricula and real-life practice, aiming to empirically investigate the shortcomings of current pedagogical approaches and propose evidence-based recommendations to enhance graduate preparedness. The methodology involved a targeted study with a test group of students, who were assessed through scenarios designed to simulate real-world professional challenges, including conflicts of interest, organizational pressures to cut corners, and psychological factors like obedience to authority. The results revealed a significant discrepancy: while students demonstrated competent theoretical knowledge of ethical codes, they proved largely ill-equipped to apply these principles under simulated organizational pressure, empirically confirming the hypothesized gap. The originality of this research lies in providing empirical validation of the inadequacies in traditional ethics education, moving beyond widespread theoretical critique. It challenges pedagogical models focused solely on abstract principles by demonstrating the decisive impact of organizational and psychological factors on decision-making and refutes the assumption that knowledge of codes is sufficient for ethical practice. Consequently, the findings have profound practical significance, providing a clear mandate for pedagogical change. They form the basis for an actionable framework for educators, advocating for the integration of experiential learning, such as high-fidelity case studies and role-playing, to cultivate practical wisdom and moral courage, thereby offering a blueprint for curriculum enhancement and a foundation for future longitudinal research.

Key words: ethics, education, methodology, societal context, decision-making, organizational pressure.

Необхідний імператив: пошук шляху у швидкоплинному ландшафті викладання інженерної етики в динамічному суспільному контексті

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Анотація. В епоху стрімкого технологічного розвитку та зростаючих суспільних очікувань ефективне викладання інженерної етики стало нагальною необхідністю. Хоча традиційні педагогічні підходи успішно навчають базовим етичним принципам та кодексам поведінки, значний масив існуючих досліджень вказує на існування критичної різниці між цими теоретичними знаннями та складними реаліями професії. Це дослідження розглядає цей існуючий розрив між абстрактними етичними принципами, що викладаються в освітніх компонентах освітніх програм інженерного спрямування, та реальною практикою, з метою емпіричного дослідження недоліків сучасних педагогічних підходів та надання науково обґрунтованих рекомендацій для підвищення готовності випускників-інженерів. Використана методологія включала цільове дослідження проведене з тестовою групою студентів, яких оцінювали за допомогою практичних ситуацій, розроблених для імітації реальних професійних викликів, включаючи конфлікти інтересів, організаційний тиск з боку керівництва та психологічні фактори. Результати дослідження виявили значну проблему – хоча здобувачі вищої освіти продемонстрували достатні теоретичні знання етичних кодексів та розуміння їх принципів, вони виявилися переважно невідповідними до їх застосування в умовах імітованого організаційного тиску, що емпірично

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підтвердило гіпотетичну невідповідність існуючого навчання інженерної етики. Оригінальність цього дослідження полягає в наданні емпіричного підтвердження недоліків традиційної етичної освіти, виходячи за межі поширеної теоретичної критики. Воно ставить під сумнів педагогічні моделі, які зосереджені виключно на абстрактних принципах, демонструючи вирішальний вплив організаційних і психологічних факторів на прийняття рішень, і спростовує припущення, що теоретичне знання етичних кодексів інженерів є достатнім для їх впровадження у життя. Виходячи із вищезазначеного, отримані результати мають глибоке практичне значення, надаючи чіткий імператив для педагогічних змін. Вони можуть бути покладені в основу дієвої програми для освітян, що буде підтримувати інтеграцію емпіричного навчання, зокрема, розгляду реалістичних кейсів, рольових ігор та симуляцій для розвитку практичних навичок, пропонуючи таким чином план для вдосконалення освітніх програм та основу для подальших досліджень.

Ключові слова: етика, освіта, методологія, соціальний контекст, прийняття рішень, організаційний тиск.

I Introduction

The significance of engineering ethics cannot be overstated. It serves as the moral compass for a profession entrusted with shaping the physical and digital worlds, directly impacting public safety, environmental health, and overall quality of life. The most fundamental tenet, enshrined in virtually every engineering code of ethics, such as that of the National Society of Professional Engineers (NSPE), is the engineer's duty to «hold paramount the safety, health, and welfare of the public» [1]. This is not an abstract ideal but a tangible commitment with life-and-death consequences. Unfortunately, the history of engineering is punctuated by failures where ethical lapses contributed to tragedy. The Hyatt Regency walkway collapse in Kansas City in 1981, where a design change was made without proper engineering review, leading to 114 deaths, serves as a stark reminder [2]. Similarly, the Challenger space shuttle disaster, meticulously analyzed by Diane Vaughan, revealed how organizational pressures and a «normalization of deviance» could override engineering concerns about safety [3]. These two infamous disasters are not merely technical failures but profound ethical ones, demonstrating the critical need for engineers to possess not only technical competence but moral courage and a steadfast commitment to public well-being. As emphasized in a widely used textbook, «Engineering Ethics: Concepts and Cases», ethical decision-making is integral to responsible engineering practice [4].

Engineering is a profession, distinguished from a mere occupation by its specialized knowledge, commitment to public service, and the trust society places in its practitioners. This trust is fragile and hard-won, as ethical conduct is the bedrock upon which this trust is built and maintained. When engineers act ethically, transparently, and responsibly, they reinforce the public's confidence in the profession. Conversely, scandals like the Volkswagen emissions deception, where engineers were implicated in deliberately designing «defeat devices» to cheat on emissions tests, severely damage this trust, not just in the company involved but in the profession as a whole [5]. As Michael Davis argues in «Thinking Like an Engineer: Studies in the Ethics of a Profession» (1998), professional ethics is about adhering to a standard of conduct that goes beyond mere legal compliance; it's about what defines a «good engineer» in a moral sense. Ethics education, therefore, plays a crucial role in instilling this sense of professional identity and collective responsibility.

Engineering is inherently innovative, constantly pushing the boundaries of what is possible. However, innovation without ethical guidance can lead to unintended and harmful consequences. As new technologies like artificial intelligence (AI), genetic engineering, autonomous systems, and big data analytics emerge, they bring with them a host of novel ethical dilemmas. Sara Baase's «A Gift of Fire: Social, Legal, and Ethical Issues for Computing and the Internet» has long been a key text highlighting the societal impact of computing technologies and the ethical questions they raise [6]. Engineers are at the forefront of developing these technologies and thus bear a significant responsibility to consider their broader societal implications, including bias in AI algorithms [7], privacy in an era of ubiquitous data collection, accountability for autonomous decision-making, and the potential for misuse. Engineering ethics provides the frameworks and cultivates the foresight needed to steer innovation in beneficial and just directions.

The impact of engineering projects on the natural environment is profound and often long-lasting, too. Engineering activities have significant environmental footprints, from resource extraction and energy production to manufacturing and infrastructure development. A growing ethical imperative within the profession is the commitment to sustainability and environmental stewardship. This involves designing products and processes that minimize environmental harm, conserve resources, reduce waste, and address the challenges of climate change. Caroline Whitbeck, in «Ethics in Engineering Practice and Research», emphasizes a problem-solving

approach to ethics, which readily applies to designing for sustainability [8]. The concept of «life-cycle assessment» and designing for the «circular economy» are technical approaches with deep ethical underpinnings, reflecting a responsibility to future generations and the planet's health.

Engineering ethics also guides professional conduct, including honesty, integrity, competence, and avoiding conflicts of interest. Engineers must be truthful in their professional reports, statements, or testimony and undertake assignments only when qualified by education or experience. They also have a responsibility to continue their professional development throughout their careers. Ethical codes provide a framework for navigating situations where personal interests might conflict with professional duties, ensuring that decisions are made in the best interest of clients, employers, and the public.

But, the education of future engineers in ethics is increasingly recognizing a crucial gap: the chasm between abstract ethical principles taught in academia and the complex, often «messy», realities of professional practice within organizations. This heightened focus on organizational dynamics, power structures, and the psychological pressures isn't accidental; it's driven by several converging factors that underscore its critical importance.

While proficient in imparting abstract ethical principles and codes of conduct, traditional engineering ethics education often fails to adequately prepare graduates for the complex realities of ethics decision-making within contemporary organizational and societal contexts. This theory-practice gap is increasingly problematic as engineers face escalating pressures from rapid technological advancements, globalization, intense market competition, complex power dynamics within organizations, and heightened public scrutiny regarding the societal and environmental impact. Consequently, engineers may find themselves ill-equipped to navigate real-world ethical dilemmas where professional responsibilities conflict with organizational pressures, personal values, or ambiguous situational factors, potentially leading to unethical conduct, harm to the public, environmental damage, or erosion of trust in the engineering profession.

This study is needed to investigate the specific shortcomings of current pedagogical approaches and identify effective strategies for bridging this gap. High-profile ethical failures in engineering highlight the severe consequences that occur when ethical considerations are inadequately addressed in practice. The existing chasm between academic ethical training and the realities of professional life suggests that current educational models may not adequately emphasize the organizational, psychological, and systemic factors that influence ethical behavior. Therefore, further research is needed to understand how engineering ethics education can be reformed to more effectively integrate these complexities, ensuring future engineers are not only aware of ethical principles but also possess the practical wisdom, courage, and skills to apply them under pressure within diverse and challenging organizational environments.

The purpose of this study is to investigate the existing shortcomings of current engineering ethics education based on the example of the Engineering and Technology Faculty students' test group. The ultimate aim is to propose evidence-based recommendations to enhance the preparedness of engineering graduates to navigate ethical dilemmas effectively and responsibly within dynamic organizational and societal contexts.

To achieve the study's purpose, the following research objectives will be pursued: to critically analyze current pedagogical approaches, content, and assessment methods in engineering ethics education to identify specific limitations in addressing problematic topics; to identify and characterize the common types of organizational pressures (e.g., conflicts of interest, pressures to cut corners, loyalty dilemmas) and psychological factors (e.g., obedience to authority, groupthink, moral disengagement) that engineers frequently encounter in professional practice and analyze students' preparedness to face them; to propose a framework or set of actionable recommendations for enhancing engineering ethics curricula and pedagogical practices to better equip future engineers for navigating the evolving landscape of ethical challenges in their professional lives.

II Materials and Methods

Engineering ethics education, while crucial, often struggles to bridge the significant gap between abstract ethical principles taught in academia and the nuanced realities of professional practice. While case studies are staples, they are often presented retrospectively with clear «heroes» and «villains» or focus on catastrophic failures. This can neglect the mundane ethical dilemmas and incremental decisions made under pressure. As Newberry discusses, there's a persistent challenge in making ethics education truly impactful and relevant to the dilemmas students will face, moving beyond simplistic applications of codes to complex situations [9].

Traditional formats often fail to simulate the pressure of real-world decision-making. Students don't experience the social dynamics or personal career risks involved in raising ethical concerns. While reviews [10] highlight various interventions, the extent to which these fully replicate organizational pressures remains challenging. Knowing the «right» thing is different from having the skills and courage to act on it effectively within an organization. Pedagogy often underemphasizes how to navigate organizational politics or communicate concerns persuasively.

Teaching engineering ethics often focuses on grand ethical theories and codes, which can seem detached from day-to-day organizational drivers like profit motives and resource constraints. There's insufficient content on organizational behavior, corporate culture, and cognitive biases. Much content frames ethical dilemmas as problems solvable by moral individuals, neglecting systemic pressures. Some researchers argue for broadening ethics teaching beyond this individualistic approach to include social ethics and the role of engineers in societal and organizational contexts, thereby addressing the systemic nature of many ethical problems [11]. At the same time, the «micro-ethics» of daily professional conduct might be underrepresented. Teaching content may not adequately help students develop a robust professional ethical identity that can withstand organizational pressures.

As for limitations, assessments often prioritize recall of codes or theories, struggling to assess ambiguous ethical reasoning or likely behavioral responses. So, the challenge lies in moving assessments beyond theoretical understanding to evaluating practical ethical competence. Of course, qualities like integrity and courage are hard to measure through traditional academic assessments, which can only add to the vagueness of the problem.

For our study, we selected 1st and 4th-year students majoring in Industrial Engineering at the Faculty of Engineering and Technology of Poltava State Agrarian University. Considering objective factors, a large and multifaceted study requires many participants and a long time. Beginning with a smaller study group of 5-10 members offers distinct advantages before potentially expanding. In this setting, members often feel more comfortable sharing ideas and asking questions without the pressure of a larger audience. Students perceive group work as beneficial for gaining new perspectives and mutual support, experiences often amplified in smaller, more manageable units [12]. This allowed more focused discussions and efficient problem-solving, ensuring everyone grasps core concepts. It's also easier to effectively communicate and share study habits within a smaller unit. Based on this, in general, 20 students were selected for participation. Each of the two groups (10 students of the 1st course and 10 students of the 4th course) holds members of the same gender, approximate age, and level of education.

At Poltava State Agrarian University, engineering ethics is introduced to students as an integral component of the mandatory first-semester, first-year discipline titled «University Education». This foundational course outlines the key characteristics of higher technical education in Ukraine, incorporating topics pertinent to real-world engineering scenarios, and is generally designed to focus on the student's adaptation to the evolving demands of higher education [13]. For the present study, first-year students were selected because they had recently covered these relevant ethical topics within the preceding 10 months of their university experience. Fourth-year students were chosen as a comparative group; they had also completed this discipline in their first year but had since augmented their theoretical knowledge with practical experience gained through several industrial practicums at different enterprises and factories. Engagement in these industrial, rather than purely academic, practicums is significant, it provides students with tangible experience in navigating multi-generational teams, direct involvement in production processes, and an understanding of organizational management hierarchies.

To effectively investigate the perceived and experienced gap between engineering ethics taught academically and the complex realities of professional practice, a multi-method approach involving interviews, questionnaires, and anonymous surveys was implemented. This allowed for in-depth qualitative insights and broader quantitative comparisons between the target groups: 1st-year students with recent theoretical ethics education, and 4th-year students who supplement this with industrial practicum experience. Before any data collection, formal approval from students was obtained. All participants were provided with a clear explanation of the study's purpose, what their participation would entail, how their data would be used and protected, their right to voluntary participation, and their ability to withdraw at any time without penalty. It was ensured that all instructions were unambiguous and easy to understand.

For the 1st year students, interviews and anonymous surveys explored understanding of ethical principles, how they anticipate applying these in professional settings, and what ethical challenges they foresee. For the 4th year students, interviews and anonymous surveys delved into how their industrial practicums have shaped their views on academic ethics, elicited specific examples of ethical dilemmas observed or experienced, and understood how they navigated workplace dynamics concerning ethical conduct. The content of these surveys and topics of interviews was somewhat based on the standardized DIT and DIT-2 tests – copyrighted psychometric instruments developed by James Rest and colleagues, now managed and distributed by the Center for the Study of Ethical Development at the University of Alabama [14]. While, of course, not the same, created engineering-specific ethical dilemmas were specifically designed to assess students' general understanding and precise application.

Interviews were conducted in April and May 2025 using open-ended questions, allowing flexibility for follow-up. The basic questions for both groups were the same – the only difference was that they asked students to give an answer based on their experiences. All interviews were held in quiet, private locations. These are some examples of asked questions: «When public safety conflicts with project cost or deadlines, how should an engineer prioritize and justify their decision?», «When an engineer's duties to their client, employer, and the public conflict, how should they determine which takes precedence?», «What key ethical issues should engineering teams proactively address at the start of any new project?», etc. Questionnaires and anonymous surveys, conducted at the same time, were used to gather specific information, enabling quantitative comparisons between 1st and 4th-year students, and to collect honest responses on potentially sensitive topics through anonymity. Surveys measured agreement and commonness of the answers with closed-ended questions, trying to gauge true feelings about pressures to act unethically, willingness to report concerns, and actual (unattributed) experiences of ethical breaches during practicums from recipients. Closed-ended questions sounded like «In a situation where an employer's demands conflict with the public's best interest, is an engineer's primary obligation always to the public?» or «Do you believe that university ethics education has adequately prepared you to identify and navigate potential conflicts of interest in professional settings?», etc. The survey was distributed through an online platform (Google Forms). Because these surveys were anonymous, no identifying information (names, specific student IDs) was collected.

Questionnaires were constructed as ethical dilemmas. The core of the dilemmas remains the same for both 1st and 4th-year students, as ethics principles are constant. The key difference lay in the depth of understanding of the contextual factors, the range of potential solutions considered, and the perceived weight of consequences based on experience. These artificially constructed dilemmas were used to reveal how experience shapes professional judgment. Each of the five dilemmas had a specific scenario covering one of the core themes selected for this study. For example, the «Inspired Design Dilemma» had the following scenario: «As a junior design engineer, you're pressed to complete a new product design. You remember a very similar, effective solution to a key problem in a publicly available technical paper from a competitor (not patented). Directly incorporating significant elements would save weeks and likely improve the product. Your company rewards rapid innovation». In this example, the main ethical dilemma is about the ethicality of «borrowing» from the competitor's public design to meet deadlines and impress your bosses. These dilemmas were discussed directly within the groups, comparing their reasoning, the factors they prioritize, and the proposed solutions, highlighting how experience (or lack thereof) shapes ethical decision-making in practice.

Despite their capacity to reveal nuanced differences, these dilemmas are intentionally designed around simple principles, such as honesty, public safety, responsibility, professional integrity, etc. The scenarios are typically straightforward, presenting clear-cut conflicts that students can readily grasp, even with limited real-world engineering experience. This inherent simplicity ensures that the fundamental ethical tension is easily understood, allowing students to engage with the core problem without being bogged down by excessive technical complexity or obscure contextual details. The goal is to provide an accessible entry point for ethical reasoning, laying a foundation before possibly exploring more intricate variations.

The comprehensive analysis of student responses employed a robust mixed-methods research design, integrating quantitative and qualitative data processing techniques to capture the full spectrum of insights. For data derived from anonymous Google Forms surveys featuring closed-ended questions, statistical analysis was conducted primarily using software packages such as advanced functionalities within Microsoft Excel. The initial phase involved generating frequencies and percentages for categorical responses to understand the distribution

of choices and opinions. Then, they were visualized using bar charts, histograms, or pie charts to provide an accessible overview. For rich textual data gathered from written open-ended questions within surveys and detailed transcripts of group discussions and individual interviews focused on ethical dilemmas, qualitative analytical methods were crucial. Qualitative content analysis focused on interpreting the meaning and significance of content within its context, examining the presence, meanings, and relationships of specific words and concepts. Narrative analysis was used for content that involved storytelling or detailed accounts of reasoning processes to understand how students construct meaning and structure their ethical arguments.

The findings from quantitative and qualitative analyses were integrated to provide a more holistic and validated understanding. For instance, detailed explanations found in open-ended answers or discussion transcripts were illuminated and contextualized by the statistical trends identified in survey responses. Conversely, themes emerging from qualitative data provided new hypotheses to be tested quantitatively in future studies.

III Results

Given the critical importance of ethics in engineering, its education cannot be a static enterprise. It must be dynamic and responsive to the evolving nature of the profession itself and the ethical challenges it faces. Early approaches to engineering ethics education often focused heavily on the memorization and application of professional codes of ethics. While understanding codes is essential, contemporary ethics education recognizes that codes alone are insufficient for navigating complex, novel, or ambiguous ethical dilemmas. As Michael Davis argued, codes are a good starting point, but true ethical competence requires developing skills in ethical reasoning, critical thinking, and moral imagination [15]. Modern pedagogy, therefore, emphasizes the development of these cognitive skills, enabling students to analyze situations, identify ethical issues, consider different perspectives, and justify their decisions based on sound ethical principles. The field has seen significant pedagogical innovation aimed at making ethics education more engaging and effective for engineering students, who are often pragmatic and problem-oriented.

Case studies remain a cornerstone, but they have evolved from simple, often decontextualized scenarios to more complex, realistic, and open-ended narratives that reflect real-world engineering, such as those discussed by M. S. Pritchard [4]. These typically include organizational pressures and stakeholder conflicts.

Different *active learning strategies* are becoming more popular. Role-playing scenarios allow students to experience ethical dilemmas from different perspectives and practice communication skills. Debates on controversial ethics issues can sharpen critical thinking and argumentation, and simulations can immerse students in decision-making processes under pressure [16].

A particularly influential, relatively recent development is the *GVV (Giving Voice to Values)* curriculum pioneered by Mary Gentile [17]. *GVV* shifts the focus from ethical analysis (identifying what is right) to ethical implementation (developing strategies to act on one's values effectively, especially in the face of opposition or organizational pressures). This approach resonates strongly with the practical orientation of engineering students and addresses the challenge of moving from knowing to doing.

As noted earlier, new technologies bring new ethical challenges. Engineering ethics education must continuously update its content to address these. This includes AI, biotechnology, and cybersecurity ethics. It's also increasingly recognized that individual ethical decision-making is heavily influenced by organizational culture, power dynamics, financial pressures, and systemic factors of one's place of employment. As such, ethics education is expanding to include concepts like groupthink, normalization of deviance, obedience to authority, ethical leadership, organizational climate, and moral distress. So, assessing the effectiveness of ethics education is a complex but crucial endeavor. This field is moving beyond simply testing knowledge of codes or theories, now, efforts are focused on assessing changes in students' moral reasoning capabilities, often using instruments like the Defining Issues Test (DIT), or developing specific rubrics to evaluate their ethical analyses in written assignments or case study responses.

In many foreign countries, accreditation bodies, most notably ABET (Accreditation Board for Engineering and Technology) in the United States, play a significant role in shaping engineering curricula, including ethics education. ABET's Criterion 3, student outcomes, explicitly requires programs to demonstrate that their graduates have «an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic,

environmental, and societal contexts» [18]. This mandate ensures that ethics remains a core component of engineering education and drives institutions to evaluate and improve their approaches continuously.

In real life, engineers frequently navigate a complex landscape where organizational pressures and internal psychological factors can significantly challenge their ethical decision-making and professional integrity. Typically, they include *conflicts of interest* that arise when an engineer's interests (financial, familial, reputational, etc.) or loyalties could improperly influence, or appear to influence, their professional judgment or actions, potentially compromising objectivity or fairness in their duties. For example, recommending a supplier in which they have a personal financial stake.

Pressures to cut corners driven by tight deadlines, budgetary constraints, or competitive demands may compromise quality, safety standards, thoroughness of testing, or ethical considerations to save time or money. This can involve using substandard materials or skipping crucial design verification steps. Engineers often feel strong loyalty to their employer, colleagues, or clients. This can create *loyalty dilemmas* and conflicts when these loyalties clash with their primary responsibility to public safety, health, and welfare, or with legal and ethical codes. For instance, being asked by a manager to conceal a design flaw from a client.

While not inherently unethical, relentless focus on meeting aggressive timelines and staying under budget (*schedule and budgetary constraints*) can create an environment where ethical considerations are downplayed or ignored, leading to decisions that prioritize project completion over safety or quality. *Pressure to conceal information* or *misrepresent data* can involve being asked to withhold negative test results, exaggerate a product's capabilities, or downplay potential risks to secure a contract, appease stakeholders, or avoid regulatory scrutiny.

Simultaneously, engineers are susceptible to several psychological factors that can impair ethical judgment, for example, *obedience to authority* – a well-documented phenomenon [19] where individuals are inclined to comply with directives from perceived authority figures, even if those directives conflict with their own ethical judgment or professional standards. An engineer might follow a superior's unethical instruction due to fear of reprisal or deference to their position. *Groupthink* occurs in cohesive groups where the desire for conformity and unanimity overrides realistic appraisal of alternative courses of action or critical evaluation of ethical implications. Individuals may suppress dissenting opinions to maintain group harmony, leading to poor and potentially unethical collective decisions.

A set of psychological mechanisms that individuals use to rationalize or justify unethical behavior, allowing them to act against their moral standards without self-condemnation, is known as *moral disengagement*. Examples include euphemistic labeling (calling bribery «facilitation fees»), advantageous comparison (comparing an unethical act to something worse), or displacing responsibility. In large teams or complex organizational structures, individuals may feel less personal accountability for the outcomes of collective actions, believing that others are responsible or that their contribution is insignificant. This *diffusion of responsibility* can lead to inaction in the face of ethical concerns.

Normalization of deviance is a gradual process where small, seemingly minor deviations from accepted standards or ethical norms become accepted practice over time. Each small step away from the ideal seems inconsequential, but cumulatively, they can lead to significant ethical lapses or even disasters, as the «abnormal» becomes the «new normal». Understanding these intertwined organizational and psychological dynamics is crucial to identifying and mitigating ethical risks, thereby upholding their commitment to public safety and professional standards. As for the results of the conducted research, the primary difficulty in numerically representing data from interviews and open-ended questions is the unavoidable loss of rich nuance and context. The researcher must interpret and code subjective, often conditional, responses into fixed categories, a process that inherently oversimplifies complex personal beliefs and introduces potential bias. Therefore, as this study is a cross-sectional analysis of existing opinions rather than a psychological survey, the charts successfully fulfill their intended purpose by providing a clear and impactful snapshot of the prevailing attitudes within each cohort at a specific moment in time.

The interview data (Fig. 1) reveal a systematic erosion of students' stated commitment to foundational ethical principles as they progress through their engineering education. While first-year students express near-unanimous agreement with core ethical tenets, fourth-year students consistently show a diminished, more cynical perspective. This suggests that exposure to the perceived realities of the profession tempers their initial idealism and forces a recalculation of what is practically achievable versus what is ethically ideal.

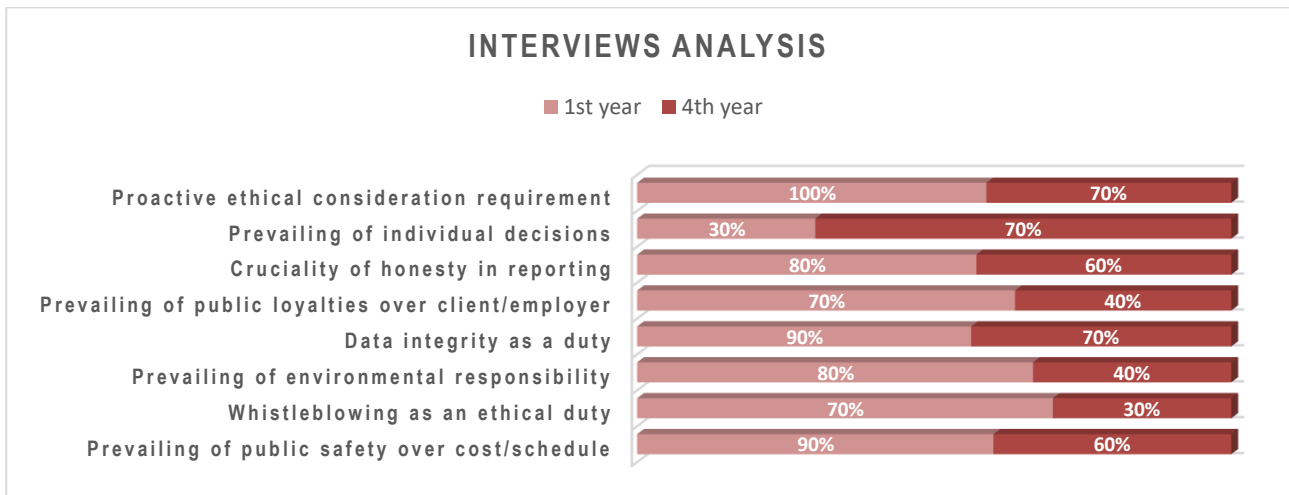


Fig. 1. Graphical representation of interview analysis

There is a stark decline in the prioritization of public good over other pressures. The belief that public safety should prevail over cost/schedule drops from 90% to 60%, and that public loyalty trumps loyalty to a client/employer fall from 70% to 40%. Similarly, commitment to environmental responsibility plummets from 80% to 40%. This indicates that senior students are internalizing the organizational and financial pressures that often conflict with their duty to the public. The most dramatic shift is seen in the perception of «whistleblowing as an ethical duty», which falls from 70% among first-year students to a minority position of 30% among fourth-year students. This aligns perfectly with previous data showing a perceived lack of support and a fear of reprisal. Senior students have clearly learned that speaking out, while ethically correct in theory, is a personally risky and often unsupported action in practice.

The only metric that increases is the «prevalence of individual decisions», which more than doubles from 30% to 70%. This is a crucial finding. It suggests that as students lose faith in organizational support systems and collective ethical standards, they conclude that ethical choices are ultimately a matter of individual, isolated struggle. They no longer see ethics as a shared, systemic responsibility but as a burden the individual must bear alone. In conclusion, the interview analysis shows that while students may enter their studies with strong ethical convictions, their educational journey – coupled with exposure to professional norms – systematically dismantles this certainty. By their final year, they are less likely to prioritize the public, far less willing to act as whistleblowers, and feel that the burden of ethical decision-making rests solely on their shoulders, highlighting a profound need for an educational model that builds resilience and provides practical strategies for upholding ethics within complex systems.

The data below (Fig. 2) also paints a vivid picture of a «reality check» that occurs as engineering students progress through their academic careers. The findings strongly suggest that as students gain more knowledge and exposure to the profession (through internships, advanced projects, and industrial practicums), their initial optimism is replaced by a soberer and critical understanding of the ethical challenges they will face. Fourth-year students are significantly more aware of the constant pressure in the field and the difficulty of real-life application of ethical principles. Their education has made them more attuned to the gap between classroom ideals and professional realities. The most telling finding is the dramatic drop in perceived «sufficiency of basic education in ethics» from 80% to 30%. First-year students enter with faith in the curriculum, but by their final year, they feel it has not adequately prepared them for the complexities of the real world. The shift from 40% to 0% on «effective engineer support and protection» is alarming. It indicates that senior students have become completely disillusioned, believing that formal systems to protect engineers who act ethically are non-existent or ineffective.

As awareness of external pressures and lack of support grows, students' confidence in their own «effectiveness of pressure resistance» is halved. They realize that navigating ethical dilemmas will be much harder than they initially thought. In conclusion, this data validates the hypothesis that traditional engineering ethics education is insufficient. It shows that as students approach graduation, they increasingly recognize the intense pressures, lack of institutional support, and practical difficulties of applying ethics, leaving them feeling vulnerable and ill-equipped for the professional world.

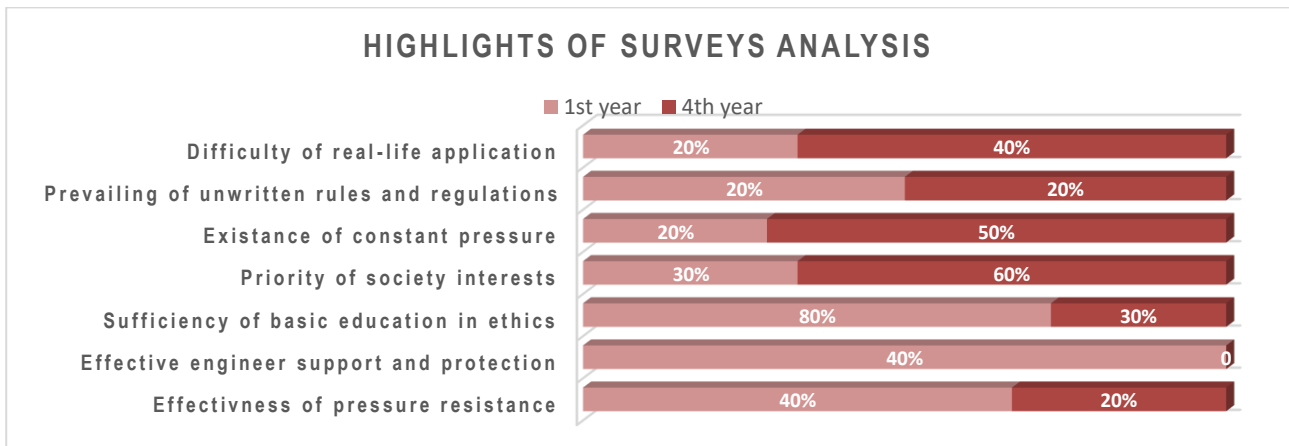


Fig. 2. Graphical representation of surveys highlights

This analysis (Fig. 3) continues to reveal a troubling erosion of ethical absolutism as students advance through their engineering education. The data indicates a consistent shift from idealistic, principle-based decision-making among first-year students to a more pragmatic, and often ethically flexible, mindset among fourth-year students. The most dramatic finding is in the «Substandard Component Dilemma». While 100% of first-year students would insist on the higher moral ground even if it caused delays, this conviction drops to 60% among fourth-year students. This signifies a major shift, where nearly half of senior students are willing to compromise on safety or quality to meet project timelines, a clear nod to perceived industry pressures. There is also a further significant increase in the willingness of senior students to make actively unethical choices. For instance, the readiness to misrepresent data to avoid conflict («Altered Emissions Data») more than doubles from 20% to 50%, and the willingness to deploy a known «Biased AI Algorithm» skyrockets from 20% to 70%. This suggests that senior students see such compromises as a more realistic or necessary part of the job.

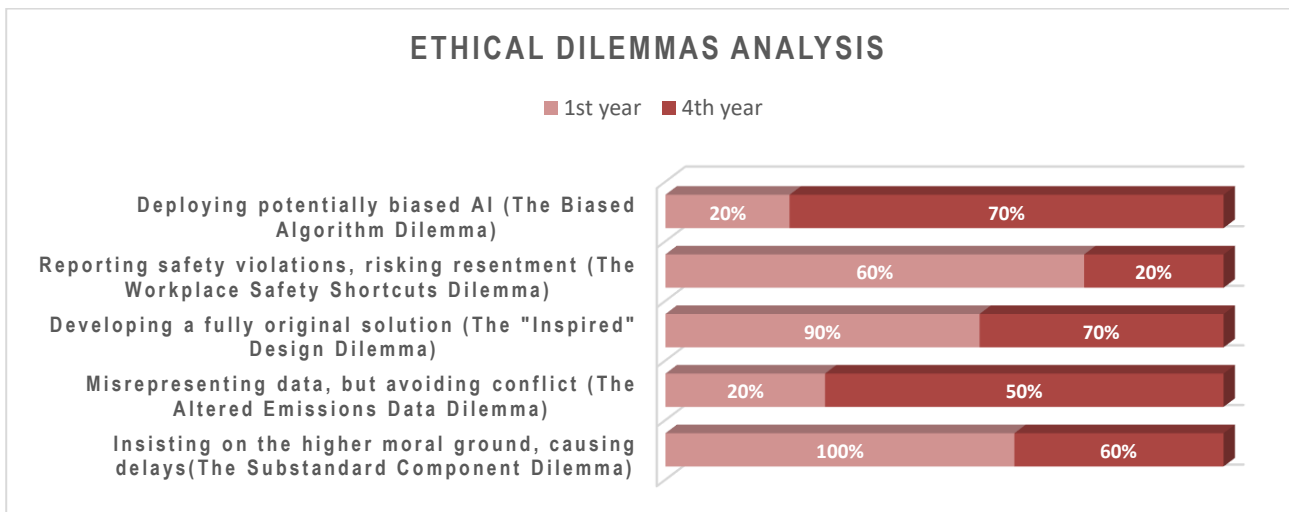


Fig. 3. Graphical representation of ethical dilemmas analysis

The «Workplace Safety Shortcuts Dilemma» provides stark evidence of how students learn to navigate organizational dynamics. The willingness to report safety violations plummets from 60% in the first year to just 20% in the fourth year. This demonstrates that senior students have become acutely aware of the personal risks associated with whistleblowing and are far less likely to challenge the status quo, aligning with the previous chart's finding of a perceived lack of engineer support. In summary, this data illustrates the «theory-practice gap» in action. Students enter their education with strong, clear-cut ethical principles. However, by the time they are ready to graduate, their perspective has been reshaped by an awareness of professional pressures, leading to a greater willingness to compromise on safety, misrepresent data, and stay silent about violations. This highlights a critical failure of current education to equip students with the skills and courage to uphold their initial ethical convictions in the face of real-world complexities.

At the same time, more seasoned students demonstrate a deeper understanding of complex contextual factors, moving beyond simplistic rule-following to consider stakeholder interests, societal impacts, and unspoken professional norms. This also typically correlates with a broader range of potential solutions considered, extending beyond immediate technical fixes to encompass communication strategies, policy adjustments, or long-term preventative measures. Consequently, the perceived weight of consequences tends to be more profound and far-reaching for experienced individuals, who are better equipped to anticipate cascading effects on public safety, environmental integrity, and professional reputation, unlike novices who might focus on more immediate or personal repercussions.

IV Discussion

Moving beyond purely theoretical instruction in engineering ethics towards more immersive, practice-oriented pedagogical approaches is profoundly important and seems like the only right step. While understanding ethical codes and philosophical principles provides a necessary foundation, it often fails to equip students for the ambiguous moral landscapes they will inevitably encounter in their careers. Immersive methods bridge this critical gap. These active learning strategies compel students to grapple with conflicting values, stakeholder interests, and the tangible consequences of their decisions.

By engaging in these practical exercises, aspiring engineers develop crucial critical thinking, moral reasoning, and communication skills under pressure. They learn to identify ethical issues proactively, analyze them from multiple perspectives, and articulate justifiable courses of action. Furthermore, such approaches foster a deeper sense of empathy and professional accountability, as students confront the human impact of engineering choices. This practical application helps internalize ethical principles, transforming them from abstract concepts into guiding tenets for professional conduct. Ultimately, this pedagogical shift not only teaches ethics but also aims to cultivate engineers with a robust ethical compass, prepared to uphold public safety, welfare, and the integrity of the profession. The recommendations below, based on the study results, ensure future engineers are not only technically proficient but also ethically astute, ready to make sound judgments in complex situations.

Implementing advanced *Case-Based Learning (CBL)* with complex and ambiguous scenarios will move beyond simplistic right-versus-wrong cases to those mirroring real-world professional life, characterized by incomplete information, conflicting stakeholder interests, significant uncertainties, and multiple viable (yet imperfect) solutions. Such scenarios integrate technical complexities with socio-ethical dimensions, forcing students to grapple with nuance [20].

Fostering *direct engagement with industry professionals* and incorporating structured interactions such as guest lectures by engineers sharing their ethical dilemmas, mentorship programs, site visits, and collaborative projects with industry or community partners. This provides students with firsthand accounts of organizational pressures and the practical application of ethical principles, as advocated in community-engaged learning approaches [21].

Employing *interactive role-playing and simulations* that design role-playing exercises where students adopt different stakeholder perspectives (e.g., project manager, junior engineer, client, regulatory body) in an ethical conflict can also be quite beneficial. Digital or virtual reality simulations [22] create immersive environments where students can make decisions under simulated pressures (like time, budget, authority) and experience their consequences in a safe space. Introducing students to various diverse established ethical theories (utilitarianism, deontology, virtue ethics, care ethics) and practical decision-making models encourages students to articulate their reasoning, justify their choices, and anticipate counterarguments.

It's imperative to cultivate a proactive, ethical mindset and professional identity in any student. *Regular reflective practice* encourages students to critically examine their values, biases, emotional responses to ethical dilemmas, and how these might influence their professional judgment and development of professional identity [10]. Explicitly discussing common pressures like conflicts of interest, loyalty dilemmas, obedience to authority, and groupthink equips students with strategies for ethical dissent, whistleblowing (and its protections or risks), and fostering ethical leadership within teams.

Longitudinal and horizontal ethics integration shifts from isolated ethics modules to weaving ethical considerations throughout the entire engineering curriculum, connecting them to technical subjects (e.g., safety factors in design, data privacy in software engineering, environmental impact in materials selection), reinforcing

the idea that ethics is integral to engineering practice. University curriculum must be dynamic, incorporating contemporary issues and social justice implications of technology [23].

The dynamism of engineering ethics education is not only a response to changes within engineering itself but is also profoundly shaped by the evolving societal context in which engineering is practiced. Societal values, expectations, and challenges are not static; they shift over time, often in response to technological advancements, cultural movements, and global events. The sheer pace of technological change, typically described as exponential, means that new technologies with significant societal impact emerge faster than society can fully comprehend or develop ethical and regulatory frameworks for them. This requires engineers to engage in «anticipatory ethics» – to proactively consider the potential ethical implications of their work before technologies are widely deployed. The pervasiveness of technology, from smartphones to IoT devices, means engineering decisions have more intimate and widespread effects on daily life than ever before, heightening ethical scrutiny.

Engineering is an increasingly global profession. Engineers work on international projects, in multicultural teams, and for multinational corporations. This globalization brings them into contact with diverse cultural norms, legal standards, and ethical expectations [24]. What might be considered acceptable practice in one culture could be ethically problematic in another, so engineering ethics education must therefore equip students with cross-cultural competence and the ability to navigate these complex ethical terrains, understanding that universal principles may need culturally sensitive application. This involves grappling with ethical relativism versus universal ethical principles. There is a growing awareness of how engineering designs and technological systems can inadvertently (or sometimes intentionally) perpetuate or exacerbate social inequalities. Examples include biased algorithms in AI that discriminate against certain demographic groups [25] or infrastructure projects that disproportionately benefit affluent communities while disadvantaging marginalized ones. Engineering ethics is increasingly incorporating principles of social justice, calling for engineers to consider the equitable distribution of benefits and burdens of their work and to design for inclusivity [26]. As the realities of climate change, resource depletion, and biodiversity loss become more urgent, societal expectations for environmental responsibility also shift. This has moved sustainability from a niche concern to a central ethical imperative – the public increasingly demands that engineering solutions be environmentally sound, contributing to a circular economy and mitigating climate impacts. Modern advances in robotics, automation, and AI are poised to transform the labor market, potentially displacing large numbers of workers across various sectors. This raises profound ethical questions about economic disruption, social safety nets, the purpose of work, and the distribution of wealth generated by these automated systems [27]. Engineers developing these technologies are not isolated from these societal impacts. Ethical considerations include designing AI systems that augment rather than simply replace human capabilities, considering the retraining and societal adjustments needed, and engaging in public discourse about the future of work in an increasingly automated world.

The validity of the hypotheses proposed in the Introduction is strongly supported by the results of this study. Indeed, traditional ethics education, while strong in principle, demonstrably leaves a significant gap between theory and practice. It can be increasingly perilous amidst escalating pressures from technological acceleration, global competition, and complex organizational dynamics. Consequently, even 4th-year students are often ill-equipped to navigate the nuanced ethical dilemmas they encounter in their professional lives. Current pedagogical models (static presentation of the content of the codes of conduct and superficial consideration of known disasters) are confirmed to inadequately address the critical organizational, psychological, and systemic factors that heavily influence decision-making. Engineers often face conflicts between their professional duties, corporate pressures, and personal values, with no clear tools to resolve them. The direct result is an increased risk of public harm, environmental damage, and a significant erosion of trust in the profession. Therefore, the call to change engineering ethics education is not merely academic but an urgent professional necessity. Integrating methodologies such as CBL (Case-Based Learning), GVV (Giving Voice to Values), and active role-playing scenarios is therefore essential, as these are the very tools that cultivate engineers who possess not just theoretical knowledge but the practical wisdom and courage to apply ethical principles under real-world pressure.

V Conclusion

This study's empirical results confirm and quantify a deeply concerning trend: the systematic erosion of ethical commitment as student progress through their engineering education. The findings starkly illustrate that while students enter their studies with strong idealistic convictions, they graduate with a more cynical, pragmatic, and ethically flexible mindset. This is evidenced by a precipitous drop in their willingness to prioritize public safety over project constraints, a profound fear of whistleblowing, and a growing readiness to make unethical compromises such as misrepresenting data or deploying biased AI. This quantifiable decline directly validates the study's central hypothesis and goes beyond the widely accepted notion of a «theory-practice gap»; it charts the very process of its formation.

These findings directly refute the implicit theory that a knowledge-based education centered on abstract principles and codes is sufficient to ensure ethical practice. Instead, this research lends powerful support to theories from social psychology and organizational behavior, demonstrating that perceived situational pressures – such as lack of institutional support and fear of reprisal – are dominant factors in shaping professional ethical decision-making. The scientific novelty of this work lies in its empirical demonstration of this «ethical disillusionment», moving the academic discourse from a theoretical problem to a measurable educational failure. It advances scientific knowledge by showing that students are not merely becoming more «realistic» but are internalizing a sense of isolation and concluding that ethics is an individual burden rather than a shared professional responsibility.

The practical significance of these results is profound and urgent. They provide a clear mandate for a fundamental change from passive instruction toward active, experiential learning. To be effective, engineering ethics education must explicitly address and simulate the organizational and psychological pressures students will face. The results can be used to design curricula that integrate high-fidelity case studies, role-playing scenarios focused on navigating conflict, and strategies for building moral courage and ethical resilience. For future research, this study lays the groundwork for longitudinal studies to track the real-world behavior of graduates from these reformed programs and for comparative analyses across different institutional settings to refine these crucial pedagogical interventions further.

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The Creation of the Methodology for a Test's Development under Study of Programming Fundamentals

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Abstract. The work goal to develop a methodology for creating tests that assess students' learning outcomes in the context of studying programming fundamentals, particularly at the secondary school level. This methodology is designed to provide both adaptability to individual learning trajectories and high precision in knowledge assessment. The research is based on the combination of Classical Test Theory (CTT) and Item Response Theory (IRT). While CTT allows for the creation of traditional, easily implementable tests based on correct answer counts, IRT enables adaptive testing by aligning task complexity with students' knowledge levels. A conceptual testing model has been developed that includes learning objectives, content structuring, measurement systems, adaptive mechanisms, and dynamic learning object modeling. The model uses a combination of student performance data and learning ability parameters to assign optimal learning trajectories. The authors developed a modular adaptive system for test generation and student monitoring. It includes an integrated feedback mechanism, allows for measuring learning progress dynamically, and generates personalized test content. The implemented software determines reliability metrics, estimates errors, and adjusts difficulty levels during testing based on real-time responses. The novelty of the approach lies in its integration of IRT theory into school-level education through a formalized model of the student as a learning object. The model includes dynamic parameters, such as individual learning potential and performance trends, allowing personalized learning path generation. The proposed solution bridges the gap between traditional test-based evaluation and modern adaptive learning technologies. The methodology can be applied in secondary education to enhance the effectiveness of programming instruction. It enables precise diagnostics of student achievements, supports differentiated instruction, and allows for monitoring the learning process in real time. The developed tool can be used by educators to automate testing, evaluate student progress, and tailor instruction to individual needs.

Key words: educational testing, adaptive testing, learning object model, student assessment, individualized learning, educational technology, knowledge evaluation.

Розробка методик складання тестів при вивченні основ програмування

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Анотація. Головна задача роботи полягає у розробці методології створення тестів для оцінювання результатів навчання учнів у контексті вивчення основ програмування, зокрема на рівні середньої школи. Ця методологія розроблена з метою забезпечення як адаптивності до індивідуальних траєкторій навчання, так і високої точності оцінювання знань. Дослідження базується на поєднанні класичної теорії тестування (СТТ) та теорії відповіді на питання (IRT). СТТ дозволяє створювати традиційні, легко реалізовані тести на основі підрахунку правильних відповідей, а IRT дає можливість проводити адаптивне тестування, узгоджуючи складність завдань із рівнем знань учнів. Розроблено концептуальну модель тестування, що включає цілі навчання, структурування змісту, системи вимірювання, адаптивні механізми та динамічне моделювання об'єктів навчання. Модель використовує поєднання даних про результати учнів та параметрів навчальних здібностей для призначення оптимальних траєкторій навчання. Автори розробили модульну адаптивну систему для створення тестів та моніторингу учнів. Вона включає інтегрований механізм зворотного зв'язку, дозволяє динамічно вимірювати прогрес у навчанні та генерує персоналізований зміст тестів. Впроваджене програмне забезпечення визначає показники надійності, оцінює помилки та коригує рівні складності під час тестування на основі відповідей у реальному часі. Новизна підходу полягає в інтеграції теорії IRT в шкільну освіту за допомогою формалізованої моделі учня як об'єкта

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навчання. Модель включає динамічні параметри, такі як індивідуальний навчальний потенціал і тенденції успішності, що дозволяє створювати індивідуальні навчальні траєкторії. Запропоноване рішення заповнює прогалину між традиційною оцінкою на основі тестів та сучасними адаптивними технологіями навчання. Методологія може бути застосована в середній освіті для підвищення ефективності навчання програмуванню. Вона дозволяє проводити точну діагностику досягнень учнів, підтримує диференційоване навчання та дає можливість моніторити процес навчання в режимі реального часу. Розроблений інструмент може бути використаний викладачами для автоматизації тестування, оцінки прогресу учнів та адаптації навчання до індивідуальних потреб.

Ключові слова: освітнє тестування, адаптивне тестування, модель навчальних об'єктів, оцінювання учнів, індивідуалізоване навчання, освітні технології, оцінювання знань.

I Introduction

Currently, a new education system is being established, focused on entering the global information and education space [1, 2]. This process is accompanied by significant changes in pedagogical theory and practice of the educational process, which are associated with adjustments to the content of teaching technologies that must be adequate to modern technical capabilities and contribute to the harmonious integration of children into the information society. Computer technologies are destined to become an integral part of the holistic educational process, significantly increasing its effectiveness. Therefore, today it is impossible to imagine the educational process without the use of computer technologies [3, 4].

Multimedia allows you to effectively demonstrate educational material. The ability to use images, text, sounds, and other visual effects makes information more vivid and interesting to study. Organizing classes using multimedia allows you to clearly demonstrate the capabilities of the software and save time, intensifying the study of educational material [5, 6, 7].

The main advantages of teaching children computer technology are as follows [8, 9, 10]:

- multimedia resources can be used to simulate various situations; such programs often include game components that enhance children's cognitive abilities and improve their perception of the material;
- the effect of visualization is achieved through the use of interactive graphics and animation systems; these technologies allow you to achieve results that cannot be achieved with a conventional textbook;
- computer technology in education allows you to individualize the learning process, making it more attractive and meaningful.

Thus, information technologies allow intensifying the learning process, making it more interactive and increasing the speed of information perception, as well as improving information processing skills. The use of information technologies makes it possible [11, 12, 13]:

1. Implement an interactive approach.
2. Increase students' cognitive activity through a variety of video and audio information.
3. Monitor progress using tests and self-assessment questions.
4. Improve students' independent information processing skills.

Success in learning largely depends on how understandable the learning material and tasks are to the student at a certain stage of learning. One of the components of success is understanding and assimilation of learning material. It is no secret that nowadays many children prefer computer games to learning the basics of science.

The following software products are widely used in school-level programming education [14, 15, 16]:

1. Scratch is based on the ideas of the Logo programming language and Lego construction sets. Using scripts presented in the form of puzzles, users can program movement and speech, change appearance, and respond to user actions.

2. Blockly is a free resource developed by Google in 2012. It is a visual programming environment that allows users to write programs by combining blocks of code with each other. The training consists of a series of games designed to teach children to solve interesting and complex puzzles. The code they write using blocks is instantly converted to JavaScript, Python, PHP, Lua, Dart, and XML.

3. In Code Combat [8], students write code starting from the first level of the game and see their changes updated in real time. This helps them quickly master syntax and teaches them to write competent code.

Based on this, a study and analysis of existing educational games and simulators was conducted. In the course of this, it was found that such software products exist, but in our opinion, there is very little educational

material. There is even less material that teaches practical skills to schoolchildren with the possibility of learning and testing, as well as the possibility of solving various tasks.

Therefore, the urgent task is to develop a method and models for assessing learning outcomes through testing in the context of learning the basics of programming.

The purpose of the work is to improve the effectiveness of assessing students' knowledge in programming fundamentals by developing and implementing an advanced test design methodology, which allows to enhance the precision, adaptability, and individualization of the testing process through the integration of modern educational technologies and psychometric approaches such as Classical Test Theory and Item Response Theory.

II Materials and Methods

There are many methods and approaches to testing students' knowledge levels. However, over the past 80 years, classical testing theory and response theory have remained the most widely used.

In school education, classical testing theory (CTT) has traditionally been the basis for creating and evaluating educational tests. It assumes that each student has a certain “true score” that we try to measure with a test [17]. CTT evaluates results based on the total number of correct answers and also uses indicators such as test reliability, average score, standard deviation, etc. This approach is widely used in daily school assessment, as well as in internal control works and thematic tests.

In lower grades, particularly in grades 5–6, CTT remains popular due to its simplicity and accessibility. It is easy for teachers to use it to create tests, check students' knowledge, and assign grades. All that is required is to count the correct answers. This approach allows you to quickly get an idea of the level of mastery of the material in the class, as well as identify topics that need to be reviewed. In addition, CTT testing does not require complex software or statistical processing, which is a significant advantage in conditions of limited resources.

However, classical theory has its limitations. It does not consider the characteristics of individual tasks, and student results depend largely on the specific set of questions. In addition, CTT does not allow for the creation of adaptive tests or the accurate tracking of individual student progress over time. Despite this, it remains a reliable and convenient tool for basic assessment in schools, especially at the primary and secondary levels [18].

Item Response Theory (IRT) is a modern methodology that allows for the accurate measurement of students' knowledge, skills, or other characteristics based on their responses to individual tasks. It began to develop actively in the mid-20th century as an alternative to classical testing theory, thanks in particular to the work of scientists such as Frederick Lord and Georg Rasch. The main idea of IRT is that the probability of a correct answer depends both on the student's level of preparation and on the parameters of the task itself (for example, its complexity and ability to “distinguish” between students with different levels of knowledge) [19].

In school education, IRT is actively used not only in large standardized tests, but also in testing younger students, particularly those in grades 5–6. For example, when assessing reading and math literacy, this method allows teachers to obtain more accurate information about each child's level of preparation. Thanks to IRT, it is possible to develop adaptive tests that automatically adjust to the student's abilities: if a child answers a question correctly, the next one will be a little more difficult, and vice versa. This reduces stress and overload for students, as the tasks correspond to their level, and also increases their motivation to complete the test.

This approach allows not only to give a grade, but also to gain a deeper understanding of each student's strengths and weaknesses, which is especially important in primary and secondary school, when the foundation for future learning is being laid. In addition, the results obtained using IRT are easy to analyze in dynamics – they allow you to track the progress of an individual student or an entire group throughout the school year.

At the same time, the use of IRT in a school context has certain difficulties. Creating tests using this methodology requires a large amount of statistical data and special software, which may not be available in some educational institutions. In addition, teachers are not always familiar with the principles of IRT, which complicates its use on a daily basis. Despite this, IRT is increasingly being introduced into school practice as a tool for more flexible and accurate assessment of student achievement.

In school practice, especially in grades 5–6, the traditional test-making method is the most common. Teachers use it to create tests and independent assignments, thematic surveys, or review tests after studying a topic. Tasks are selected in accordance with the curriculum, most often from textbooks or their own work. Such

a test usually contains multiple-choice questions, matching tasks, or short-answer questions. The main goal is to check how well the student has mastered the specific material.

The advantage of this approach is its simplicity and speed of implementation. The teacher independently creates the test, focusing on the level of preparation of the class, and assessment is usually based on the number of correct answers. In grades 5–6, this format is convenient because students are not always able to work with complex or analytical tasks, and it is easier for them to answer clear, specific questions. The traditional method also allows for flexible variation of tasks depending on the class and learning situation.

The IRT-based method is less commonly used in secondary schools, but is gradually being introduced into the assessment of educational outcomes at the state or regional level. Such tests are often conducted online or in the form of notebooks, where different students may have different sets of tasks.

The advantage of this approach for schools is more accurate and flexible assessment, which allows them to identify not only overall performance but also the strengths and weaknesses of each student. For example, two students may have the same grade on a topic, but one performs well on basic tasks, while the other performs well on more complex ones. IRT research helps schools and teachers better plan their future work: who needs help, who needs additional workload [20].

Although IRT tests require more organizational effort to implement, they are gradually becoming part of school assessment practices, especially when it comes to monitoring the quality of education rather than just assessing a subject or semester. In the future, these two approaches may complement each other: traditional methods for teachers' daily work and IRT for systematic assessment and support of students' individual learning paths.

III Results

To implement a set of adaptive testing procedures, it is necessary to define a conceptual model that describes the functional units of the system as a whole. We propose a model consisting of the following blocks.

Learning objectives block. Learning objectives determine the success of the learning process. Therefore, their content and specific formulation are the most important steps in the technological design of the learning process. When setting learning objectives within a subject, the main task is as follows: for each section and topic of the curriculum, the teacher must determine the degree of success in mastering the necessary knowledge, skills, and Learning objectives can be formulated using a system of requirements for the quality of knowledge. Objective and adequate measures of learning success – tests, assignments, exercises, control tasks, control works, computer modeling – can be used at all levels of the hierarchy of learning goals.

Content block. The educational cycle should ensure consistent orientation of learning towards the set goals. Thanks to this structure, the learning process becomes “modular” in nature, allowing for maximum consideration of rapid changes in content and differentiation among students.

Measurement block. The mathematical model of adaptive knowledge control determines the level of student learning depending on the complexity of the tasks. The theoretical basis of adaptive control is IRT theory combined with the didactic principle of individualization of learning. The goal of student differentiation is served by the construction of individual curves based on the two-parameter Rasch model.

One of the most significant advantages of IRT is the measurement of student parameter values and test tasks on the same scale, which allows the level of knowledge of any student to be correlated with the degree of complexity of each test task [15]. It is on this property of parameter and task assessments that the organization of modern adaptive knowledge control is based.

Adaptive learning block.

1) Learning models.

Information technologies have a decisive impact on all stages of the learning process: from providing students with knowledge, skills, and abilities to monitoring their assimilation, while ensuring such important characteristics of learning as quality, selectivity of material, consideration of individuality, constant monitoring and self-monitoring of material assimilation, and high efficiency of teacher resource utilization.

2) Pedagogical technologies.

A technological approach to the learning process guarantees the achievement of the set learning goals. Operational feedback, which permeates the entire learning process, is the basis for the consistent orientation of learning towards its goal. Thus, the distinctive features of the technological design of the learning process are:

- specifying learning objectives in the cognitive domain, developing learning units as benchmarks for the assimilation of learning material by all students in the class;
- creating a system of assessment tests (diagnostic tests, adaptive tests);
- selection of quick test verification tools (computer programs);
- preparation of special corrective methods (short specific texts containing the necessary theoretical information, simulators);
- additional tasks, repeat tests.

It is important to know whether the student has memorized or mastered the basic minimum. The rest of the material is studied with a focus on involuntary memorization, which expands the capabilities of each student engaged in active creative activity.

This makes it possible for a given student to choose a set of test tasks appropriate to their level. This process requires computer technology for creating and storing tests, conducting testing, and processing test results. A program has been created to process test results, allowing parameters such as reliability, measurement error, correlation, etc. to be determined.

3) Effective test measures allow the level of learning of each student to be determined after studying a course module and the individual dynamics of the student's development to be determined after completing the entire course.

Monitoring system block. By monitoring in the “teacher-student” system, we mean a set of control and diagnostic measures determined by the purpose of the learning process and providing for the dynamics of students' mastery of the material and its correction. In other words, monitoring is a continuous control activity in the teacher-student system that allows observing (and adjusting as necessary) the student's progress from ignorance to knowledge. Monitoring is the regular tracking of the quality of knowledge and skill acquisition in the learning process.

Monitoring differs from conventional knowledge assessment in that it provides teachers with immediate feedback on the level of students' mastery of the required learning material. The monitoring system includes the creation of tools for assessing knowledge and skills and corrective methods focused directly on the student's personality, considering their individual achievements in the learning process.

One of the most important aspects of the computerized learning process is the interaction between the student and the learning system. To create an effective computerized learning system, the following models must be developed:

- learning object model;
- course content model;
- course mastery model;
- testing model.

The learning object model is one of the basic components of adaptive computer systems. It contains sufficiently complete information about the learning object, i.e., the student, namely: their level of knowledge, skills, and abilities, learning ability, individual characteristics (personality type and orientation, memory characteristics, attention, temperament, character, and degree of motivation for the subject being studied), and other parameters. The model is dynamic, i.e., it changes during testing, during the operation of the system.

Всі параметри моделі об'єкту навчання можна розділити на дві складові:

$$MO_D = \{MO_F, MO_P\}. \quad (1)$$

The MO_F component is a system of mandatory parameters for the learning object model. This component of the model is processed automatically by the system. Its use facilitates work with the tools and reduces development time. The second component of the MO_P contains a system of parameters that is determined by user behavior when solving a complex problem. These parameters can vary significantly for different users in the system.

Let's define the list of model parameters. To study any training course, a certain initial potential of knowledge, skills, and abilities is required, which the learning object must possess. Let us denote the integral numerical assessment of the student's initial potential as Z . Representing the process of knowledge

accumulation as the accumulation of information potential d_i over the time interval between two training-testing sessions d_τ , we write:

$$d_i = P \cdot (I_p - Z) d_\tau \quad (2)$$

where I_p is information capacity of a computer system, P is parameter “ability to learn”.

Hence,

$$P = \frac{d_i}{(I_p - Z) d_\tau} \quad (3)$$

In turn, the parameter “ability to learn” can be discretized on a fuzzy scale with a set of values “low”, ‘medium’, “high”:

$$P = \{L, M, H\}.$$

Then, the set of possible initial states of the learning object is the Cartesian product of the sets Z and P :

$$Z \times P = \{(L, L), (L, M), (L, H), (M, L), (M, M), (M, H), (H, L), (H, M), (H, H)\}. \quad (4)$$

As a result of the initial assessment, it can be determined that at the beginning of a new course, a student is in one of the possible initial states defined by the elements of the set $Z \times P$. This set has nine elements, so at least as many learning trajectories should be provided for in the course.

Then each student can be included in one of nine groups with a given individual learning trajectory, which determines the initial settings and is the basis for further work with the learning object. After dividing the students into groups according to their initial data, it is necessary to determine the learning objectives and a subset of the material to be studied for each of these groups. Thus, different models of the learning object will correspond to different models of content and mastery, each of which will have a final goal. The final goal of the training course is the knowledge, skills, and abilities that the student must acquire in the learning process in accordance with the educational program.

Considering the above, a formal description of the learning object model can be represented by a tuple of the form:

$$MO = \langle Z, P, TH, PAT \rangle, \quad (5)$$

where TN is the selected learning trajectory (a set of content and learning models), PAT is the learning trajectory adjustment procedure.

Testing allows you to determine the value of parameter P and select the learning trajectory TN in the PAT trajectory adjustment procedure.

Parameter P is an additive criterion that considers weighted assessments obtained from the analysis of answers and their comparison with the knowledge of an expert used in solving the proposed tasks.

Based on the test results, the learning object model is adjusted. For example, if a student answers test questions correctly during adaptive testing, the difficulty of subsequent tasks increases; if they answer incorrectly, the difficulty decreases. In addition, adaptive tests include additional questions on topics that the student does not know very well in order to more accurately determine their level of knowledge. The achievement of the final learning goal is verified by means of a final test, which is compiled in accordance with the working program of the training course.

The presented methodology was implemented in the software application “Automated learning system for studying the basics of programming” (Fig. 1). The app is available in Ukrainian, as it is aimed at students in Ukrainian schools.

Creating tests consists of two parts. In the first part, the teacher enters the name of the test, the maximum score that can be obtained, the number under which the test will be displayed in the topic, and the topic to which it will relate. In the second part, the teacher opens the test editor, in which they specify the number of questions, the number of answers for each question, and which answers are correct.

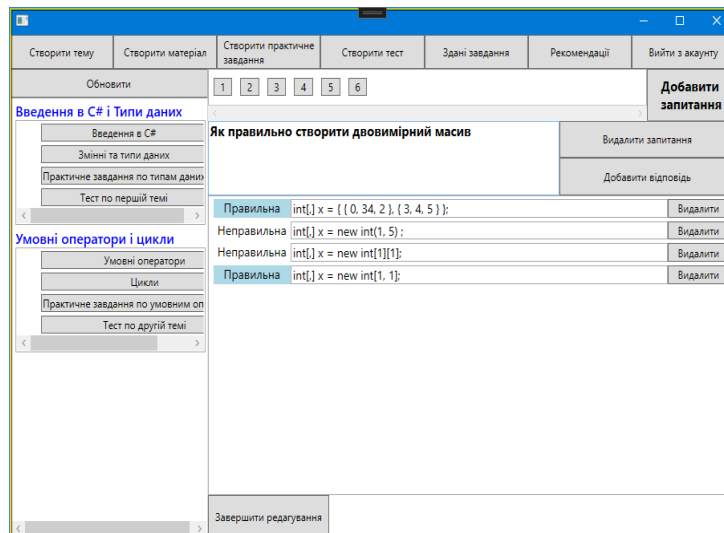


Fig. 1. Test question creation page

IV Discussion

The implementation of testing methodologies based on both Classical Test Theory (CTT) and Item Response Theory (IRT) reveals a number of practical and pedagogical implications. CTT, being simple and accessible, is well-suited for day-to-day classroom activities, especially in lower grades. However, its limitations – such as the inability to account for task complexity or learner variability – necessitate more advanced approaches in modern educational environments.

IRT, on the other hand, offers deeper insights into student performance by considering both the difficulty of test items and the proficiency level of each student. Its use allows for adaptive testing, which aligns more closely with learners' individual capabilities. The results of our study confirm that applying IRT principles in adaptive testing not only enhances test accuracy, but also increases student motivation and reduces test anxiety by providing balanced and personalized challenges.

However, the integration of IRT-based systems in secondary education poses organizational and technical challenges. These include the need for specialized software, statistical analysis tools, and teacher training. Despite these barriers, the benefits of adaptive systems – such as individualized learning paths and real-time monitoring – outweigh the implementation effort.

Furthermore, the proposed conceptual model, which includes content, measurement, and feedback components, promotes a systematic approach to learning and testing. It fosters a cycle of continuous improvement where feedback directly informs teaching strategies and student support. Thus, the hybrid uses of CTT and IRT enhances the assessment process, making it more informative, student-centered, and pedagogically effective.

V Conclusion

The study presents a comprehensive methodology for developing educational tests aimed at improving the quality of student assessment in the context of programming fundamentals. By combining traditional and adaptive testing approaches, the proposed solution addresses the limitations of conventional evaluation systems and introduces an individualized, technology-driven testing environment.

The designed model incorporates learning objectives, content modules, adaptive control mechanisms, and a detailed monitoring system. These elements are unified under a dynamic model of the student as a learning object, which enables precise identification of knowledge gaps and selection of optimal learning trajectories. This significantly improves both the reliability and diagnostic value of the testing process.

The application of IRT principles plays a key role in advancing adaptive testing. By correlating task difficulty with student proficiency, the system ensures fairness and effectiveness in assessment. This leads to better-informed pedagogical decisions and supports the personalization of learning experiences. The developed

software tool automates test generation, analysis, and feedback, making it a practical resource for educators in everyday teaching.

Ultimately, the research confirms that adaptive testing not only enhances the accuracy of knowledge evaluation, but also actively contributes to improved educational outcomes. The methodology can be adapted for different subjects and levels of education, making it a scalable and sustainable solution for modern schools. Future work will focus on refining the adaptive algorithms and expanding the system for broader application.

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Development of a Web-Based Mnemonic Training System for Business Company Employees

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Abstract. The purpose of the work is to develop a web-based mnemonic training system tailored for business company employees. The system aims to improve the memorization, processing, and reproduction of business-specific information, particularly for employees in customer service and sales. The work applies a twofold approach: design and development of a flexible web-based application and the theoretical formulation of its underlying architecture and user roles. The platform includes modules for user registration, training course administration, test generation, result tracking, and statistical analysis. The system model is described using set theory and includes interactive and adaptive interfaces, secured access, and individual training history. The developed system offers functionality for mnemonic training management: test creation, group formation, performance tracking, and data visualization. It supports multimodal information input (visual, verbal, associative) and applies gamified and adaptive techniques. It allows personalized feedback and provides mentors with analytical tools to monitor user progress. Unlike existing mnemonic tools that focus on isolated techniques or experimental applications, this system integrates classical mnemonic methods with modern web technologies in a scalable and user-oriented framework. It enables corporate training environments to incorporate memory development techniques seamlessly. The system can be implemented in real business settings to enhance staff performance, reduce error rates, accelerate employee onboarding, and foster continual professional growth. It is applicable across departments and adaptable to different knowledge domains within a company, contributing to improved efficiency of business processes.

Key words: information technology in education, professional training, corporate education, gamification, mnemonic training.

Розробка веббазованої системи мнемотренінгу працівників бізнес-компаній

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Анотація. Метою роботи є розробка веб-орієнтованої мнемонічної системи навчання для працівників бізнес-компаній. Система спрямована на покращення запам'ятовування, обробки та відтворення бізнес-специфічної інформації, зокрема, для працівників сфери обслуговування клієнтів та продажів. У роботі застосовано подвійний підхід: проектування та розробка гнучкого веб-додатку і теоретичне формулювання його базової архітектури та ролей користувачів. Платформа включає модулі для реєстрації користувачів, адміністрування навчальних курсів, генерації тестів, відстеження результатів та статистичного аналізу. Модель системи описана з використанням теорії множин і включає інтерактивні та адаптивні інтерфейси, захищений доступ та індивідуальну історію навчання. Розроблена система пропонує функціонал для управління мнемонічним навчанням: створення тестів, формування груп, відстеження успішності та візуалізації даних. Вона підтримує мультимодальне введення інформації (візуальне, вербальне, асоціативне) і застосовує гейміфіковані та адаптивні методи. Вона забезпечує персоналізований зворотній зв'язок і надає менторам аналітичні інструменти для моніторингу прогресу користувачів. На відміну від існуючих мнемонічних інструментів, які зосереджені на ізольованих техніках або експериментальних додатках, ця система інтегрує класичні мнемонічні методи з сучасними веб-технологіями в масштабованій і орієнтованій на користувача структурі. Вона дозволяє корпоративним навчальним середовищам безперешкодно впроваджувати методи розвитку пам'яті. Система

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може бути впроваджена в реальних бізнес-середовищах для підвищення ефективності роботи персоналу, зниження рівня помилок, прискорення адаптації співробітників і сприяння постійному професійному зростанню. Вона може бути застосована у всіх відділах і адаптована до різних галузей знань у компанії, що сприяє підвищенню ефективності бізнес-процесів.

Ключові слова: інформаційні технології в освіті, професійне навчання, корпоративна освіта, гейміфікація, мнемонічне навчання.

I Introduction

In today's information society, the ability to quickly and efficiently process, store, and reproduce large amounts of information is critically important. This applies to both formal education systems and professional training based on intensive knowledge acquisition. At the same time, numerous studies show that traditional forms of memorization are ineffective in the context of the modern load on human cognitive resources [1, 2, 3]. One promising solution is the introduction of mnemonic training – a system of exercises based on the use of mnemonics (methods of encoding information into easily reproducible forms).

It has been scientifically proven that regular use of mnemonics activates long-term information retention processes, promotes neuroplasticity, and increases memory performance [4]. In particular, training using the loci method (memory palace) changes the functional networks of the brain, bringing them closer to the neural patterns' characteristic of memory champions [5]. Despite this, most well-known mnemonics require special mastery, independent formation of associations, and visual imagination, which can be difficult for users without cognitive training or motivation.

In this regard, there is a need to develop information technology that would automate and personalize the process of mnemonic training. Such an approach not only lowers the barrier to entry but also makes the technology scalable for a wide range of users. For example, in [6], a system for the automatic generation of verbal and visual mnemonics for vocabulary learning using artificial intelligence models is proposed. The participants in the experiment demonstrated better results in memorization compared to traditional methods.

Another promising direction is the generation of mnemonics using music. Study [7] presents the KoroT 3E platform, which creates personalized musical mnemonics for complex concepts in computer science. This approach combines emotional reinforcement with multichannel learning and contributes to a significant improvement in memory [8].

The study [9, 10, 11] also notes the effectiveness of digital platforms that integrate mnemonics into the educational process using ICT, especially in combination with visualization, serious games, and adaptive learning.

Special attention should be paid to review [10], which proposes the use of AR/VR environments to increase user engagement in the process of mnemonic training. This confirms the feasibility of combining classical principles of mnemonics with modern visualization tools and artificial intelligence, which forms the basis for the creation of innovative information technology.

Thus, the development of information technology for mnemonic training is relevant in both theoretical and practical terms. Its development will allow for the implementation of individual learning trajectories, the automation of effective mnemonics, and a high level of user motivation through gamification, adaptation, and multimodality.

At the same time, the development of information technologies, in particular artificial intelligence systems, adaptive learning, gamification, and augmented reality, opens up new opportunities for automation, personalization, and scaling of the mnemonic training process [12, 13, 14, 15]. There are isolated examples of such solutions being implemented – for example, a system for automatically generating mnemonics using language models – but the existing solutions are mostly experimental and do not cover the full cycle of memory training with the integration of user data, progress, feedback, and flexible adaptation to the user's learning style.

Thus, the problem of developing universal and accessible information technology that combines the advantages of classical mnemonics with the capabilities of modern digital solutions to ensure purposeful, adaptive, and effective memory training remains unresolved today [16, 17, 18]. Such technology should consider the cognitive characteristics of users, ensure the automatic creation of mnemonic associations, support multimodal information presentation, and stimulate motivation through game mechanics and progress visualization [19, 20].

This paper focuses on a narrower subject area: the use of mnemonic training in the preparation of company employees.

In today's highly competitive and rapidly developing service sector, a company's success largely depends on the quality of customer service, the speed of decision-making, and the professional training of its staff.

One of the key factors for effective employee performance is a well-developed memory and the ability to quickly memorize, process, and reproduce information. This is especially true for sales managers and employees who work with a large number of customers, documentation, product items, and lease terms.

The web-based memory training system allows employees to regularly train different types of memory (working, associative, visual, etc.) in a convenient online format without interrupting their main activities. Its flexibility and accessibility promote an individual approach to learning, increase motivation for self-development, and allow exercises to be adapted to the specifics of the company – for example, using its own products, terms, or situational models in training tasks. Understanding and using the basic principles of mnemonics in a virtual environment can significantly improve learning efficiency, increase memorization, and promote the sustainable development of cognitive skills. In this context, the mnemonics training system becomes an essential tool for learning and development that meets the needs of the modern educational process.

The implementation of such a system will contribute to improving the professional level of staff, reducing the number of errors in working with customers and goods, reducing the time required to train new employees, and generally increasing the efficiency of business processes.

The purpose of the work is to develop a web-based mnemonic training system tailored for business company employees, which allows to improve the memorization, processing, and reproduction of business-specific information, particularly for employees in customer service and sales.

II Materials and Methods

When developing the system, we distinguish two areas of responsibility:

1. Development of a web-based system.
2. Preparation of materials for mnemonic training.

The web-based system being developed must meet the following functional requirements: a flexible, adaptable system that can be scaled according to the company's needs; an attractive, modern interface; a module for monitoring learning outcomes. Accordingly, the development and implementation of materials for mnemonic training is not the task of this work.

Therefore, the following tasks have been identified for the development of the web-based system:

1. Design the architecture of a web-based service that includes modules for training exercises, results tracking, and user administration.
2. Provide an interactive user interface that supports adaptability to workload, individual progress, and feedback.
3. Implement a system for collecting and analyzing training statistics that allows evaluating the effectiveness of the service for individual users and teams.

Let's consider the concept of the system being developed. The system must be easily accessible. That is why the decision was made to develop a web-based system. It can be deployed on any hosting. The system must provide a certain level of confidentiality and security. All users must register in the system and receive their own login and password. Each user can act as a student or mentor. Students undergo mnemonic training and testing to check the material they have learned. At the same time, when a student joins a separate training course, they give the author of that training course the right to view and analyze their test results. The student themselves has the right to view their own metrics and test results. Mentors are the owners of their own training courses, have full control over the materials, and can view the testing statistics for their materials. In addition, mentors have the right to control access to the training course they have created: the training course can be accessible to everyone; only to specific users; or only to users who belong to a specific group.

Thus, the key functional tasks of the system under development include: 1. Accounting for system participants. 2. Accounting for created trainings. 3. Control of the amount of information learned. 4. Monitoring the learning and memorization process. 5. Analysis of mnemonic training results.

Now let's look at the movement of information flows in the system.

The main external entities of the system are the mentor and the user. The mentor can enter input data and receive reports on the results of mnemonic training. The user creates requests to work with the system and receives monitoring of their own results.

A mentor can create their own training using proprietary materials for mnemonic training. If a mentor decides to give mnemonic training to specific individuals, they can create a group and invite other users to join it. After users complete the mnemonic training, the mentor will see the results for each of them.

Users can sign up for and complete mnemonic training courses that are publicly available or to which they have been invited. After completing the training, users can view their results.

This system allows any company employee to organize and conduct the necessary mnemonic training at any time. For example, an occupational safety specialist can conduct training on ensuring a safe working environment and compliance with safety rules in the workplace. When it comes to training different specialists with different job specifications (e.g., IT department, drivers, cleaners), it is enough to allocate a separate group for these specialists.

Since mnemonic training materials and test forms can vary in nature, it is better to use a non-relational database to store information in the system. The structure of this database will look as shown in Fig. 1.

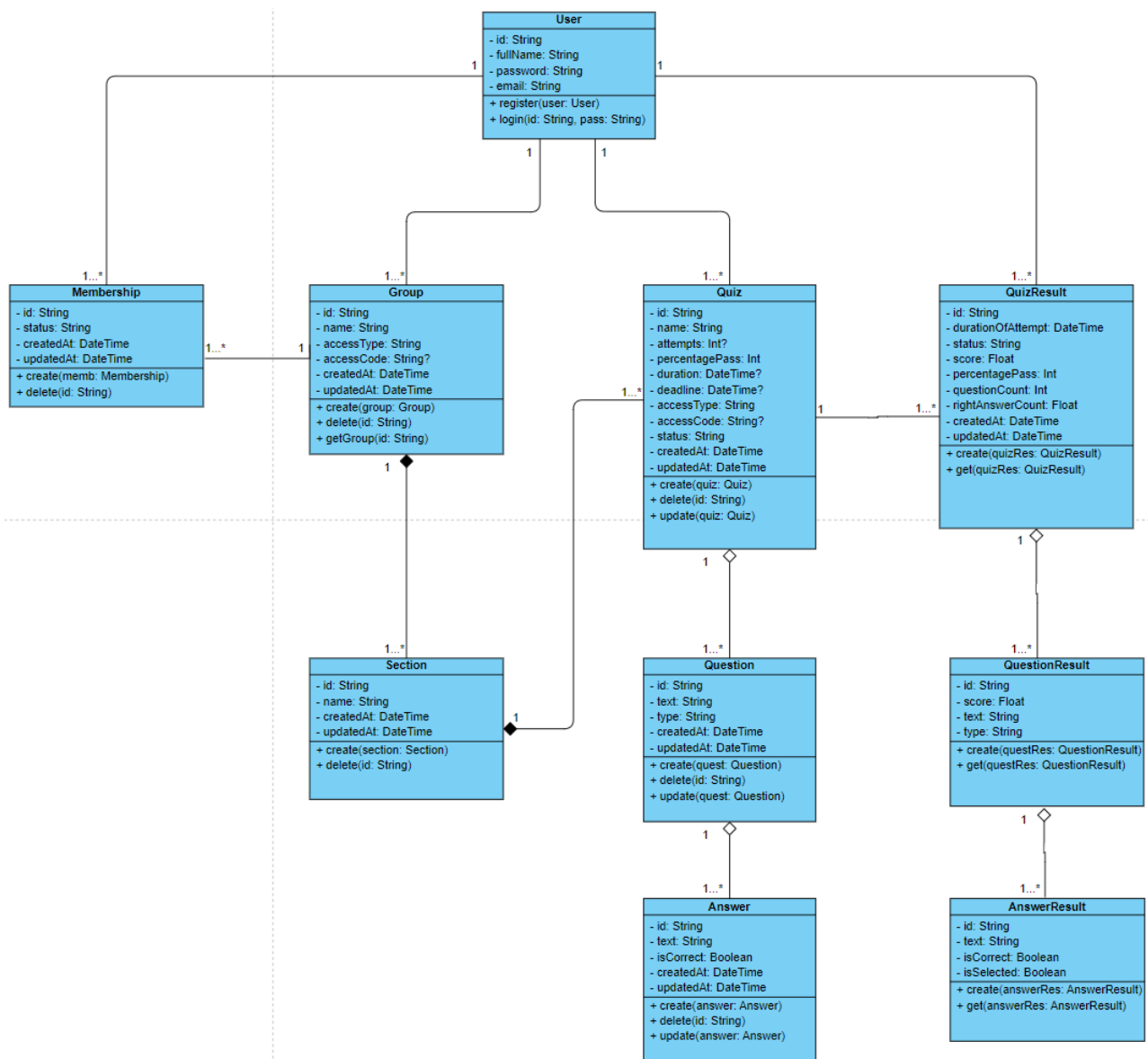


Fig. 1. Class diagram

The User class contains basic information about the user. It has methods for registration and login. The Group class represents a group of users. It contains the name, access type, and access code. It is linked to users through a “many-to-many” relationship via the Membership class. The Membership class is a linking class between User and Group. It tracks the status and timestamps of membership creation/updates. The Section class represents a subgroup. It contains a name and timestamps. The Quiz class represents the main component for testing. It contains a name, number of attempts, and passing percentage. It has time limits (duration and deadline). It is linked to questions (Questions). The Question class represents a single test question. Contains the question text and its type. Linked to answers (Answers). The Answer class contains the answer text. Has a correctness flag (isCorrect). The QuizResult class stores the test results. Contains the total score and the percentage of correct answers. Linked to specific answers via QuestionResult. The QuestionResult and AnswerResult classes store detailed information about the answers to specific questions. They track the selected answers and their correctness.

Various types of tests will be used to evaluate the effectiveness of the training, and the number of correct answers will be recorded accordingly. We will use a theoretical set model to describe the system. The system is described by a tuple:

$$S = \langle U, A, T, M, R, I, E \rangle, \quad (1)$$

where U is the set of system users (User),

$$U = \{u_1, u_2, \dots, u_n\},$$

where each user has attributes: login, role (administrator, user), progress, training history.

A – set of authentication data,

$$A = \{(u_i, p_i)\},$$

where p_i is user password or access token n_i .

T – a set of memory training exercises (Tasks),

$$T = \{t_1, t_2, \dots, t_m\},$$

each exercise has a type (visual, verbal, associative, etc.), difficulty level, input data, and expected answer.

M – a variety of techniques/mnemonics used,

$$M = \{m_1, m_2, \dots, m_k\},$$

for example: the locus method, acronyms, visual associations, spaced repetition, etc.

R – multiple exercise results,

$$R = \{r_{ij}\},$$

where r_{ij} is result of the test t_j by user u_i (point, time, correctness).

I – user interface, defined as a set of screens, controls, and navigation elements:

$$I = \{i_1, i_2, \dots, i_l\},$$

which includes login forms, access to exercises, and viewing statistics.

E – a set of feedback elements (Evaluation),

$$E = \{e_1, \dots, e_q\},$$

which provide personalized recommendations, tips, and progress reports.

The following indicators are used for statistical data processing:

1. Average score (averageScore),

$$averageScore = \left(\frac{1}{n} \sum_{i=1}^n s_i \right),$$

where n is number of tests; s_i is number of points scored in the i -th test.

2. Percentage of tests taken (passed):

$$passed = \left(\frac{1}{n} \sum_{i=1}^n p_i \right),$$

where $p_i \in \{0,1\}$ whether passed the i -th test (1 – passed, 0 – not passed).

3. Average test completion time (averageTime):

$$avarageTime = \left(\frac{1}{n} \sum_{i=1}^n t_i \right),$$

where t_i is time taken to complete the i -th test in milliseconds.

III Results

The web-based mnemonic training system developed as a result has the following main functional features:

1. Test creation module – users can create various types of test tasks.
2. User test completion – registered users can take tests created by other system participants or tests to which they have access through participation in a specific group.
3. Group creation and management system – users can create study groups, invite other users to join them, add tests to groups, and track participants' results. This allows you to organize training in classes, clubs, teams, or even individual micro groups.
4. Analytics and progress tracking – each user has a personal profile that stores information about test completion.
5. Content search and filtering – the information system provides convenient search and filtering of tests and groups.

Figure 2 shows a fragment of the web application's home page. The home page plays a key role in forming the first impression of the system, so it contains basic information that helps to immediately attract the user's interest.

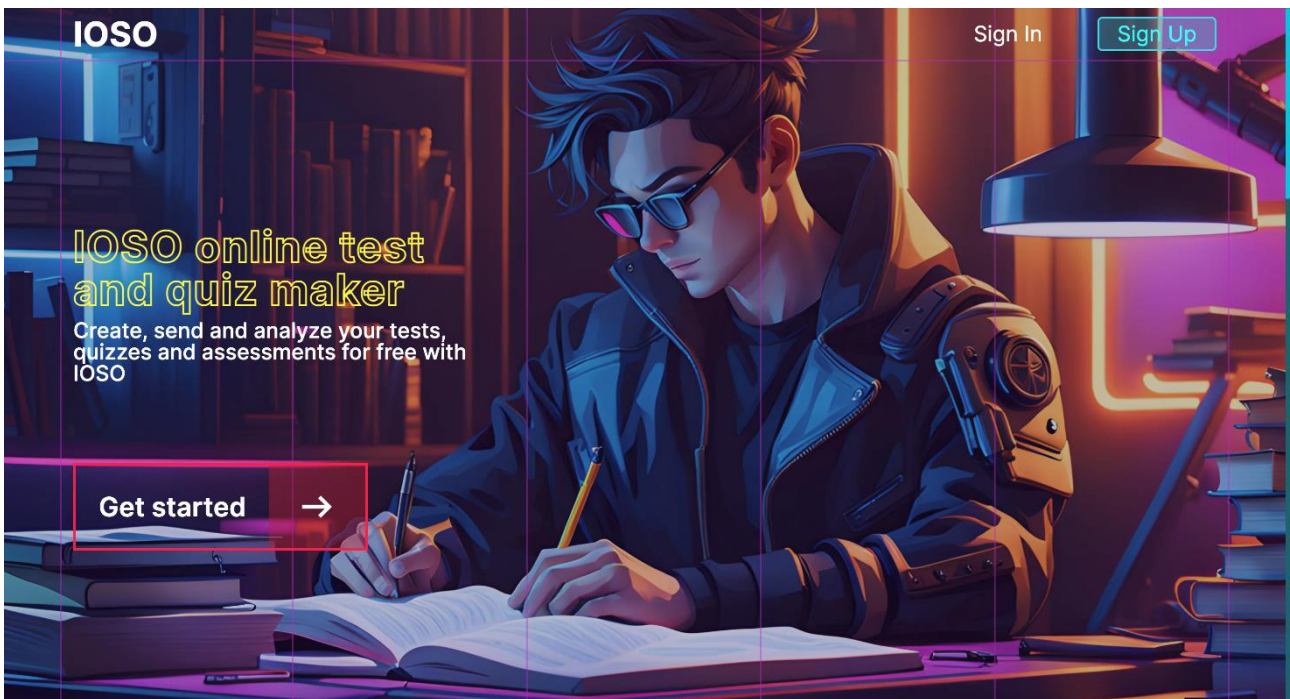


Fig. 2. Home page

Figure 3 shows the authorization page, which provides secure user access to the system. The page contains mandatory fields for entering an email address and password, which allows the user to be identified and granted access to personalized functionality.

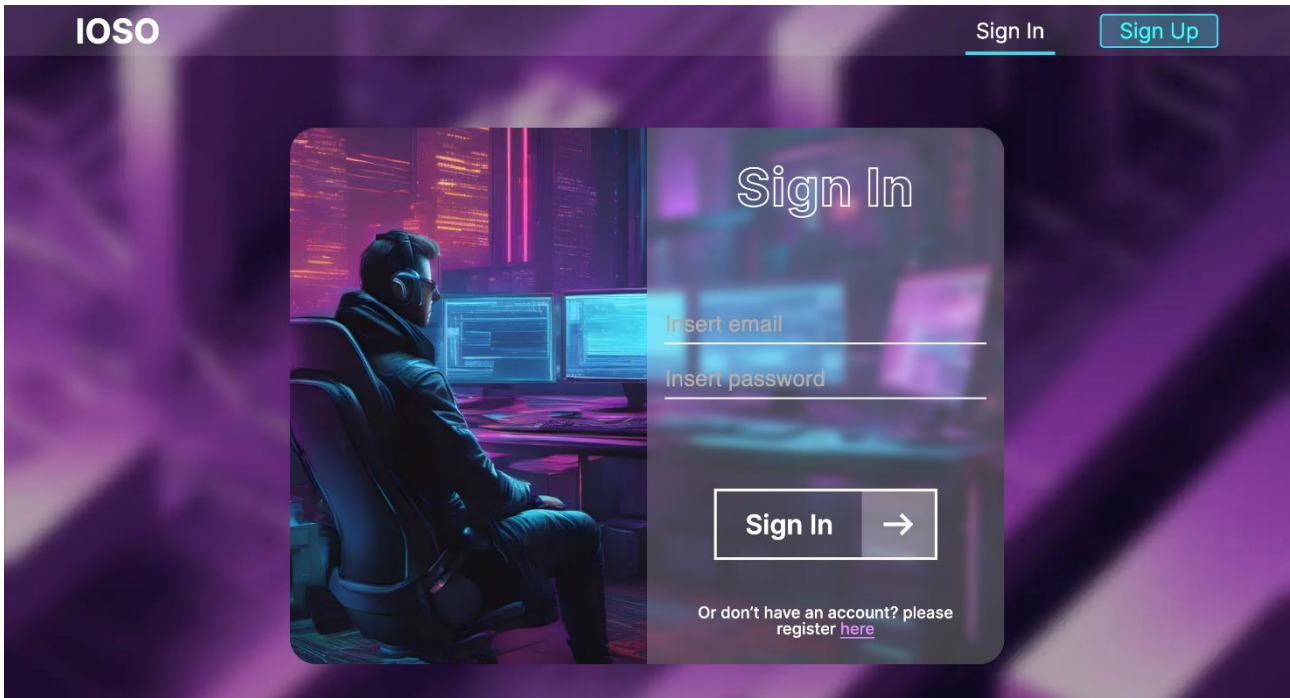


Fig. 3. Authorization page

Figure 4 shows the registration page, which is an important part of user interaction with the web system. It allows users to create a new account, which is necessary for further use of the platform's functionality. The page contains mandatory fields for entering your full name, email address, and password. This data is used to create a unique user profile, as well as to identify and personalize access to the system.

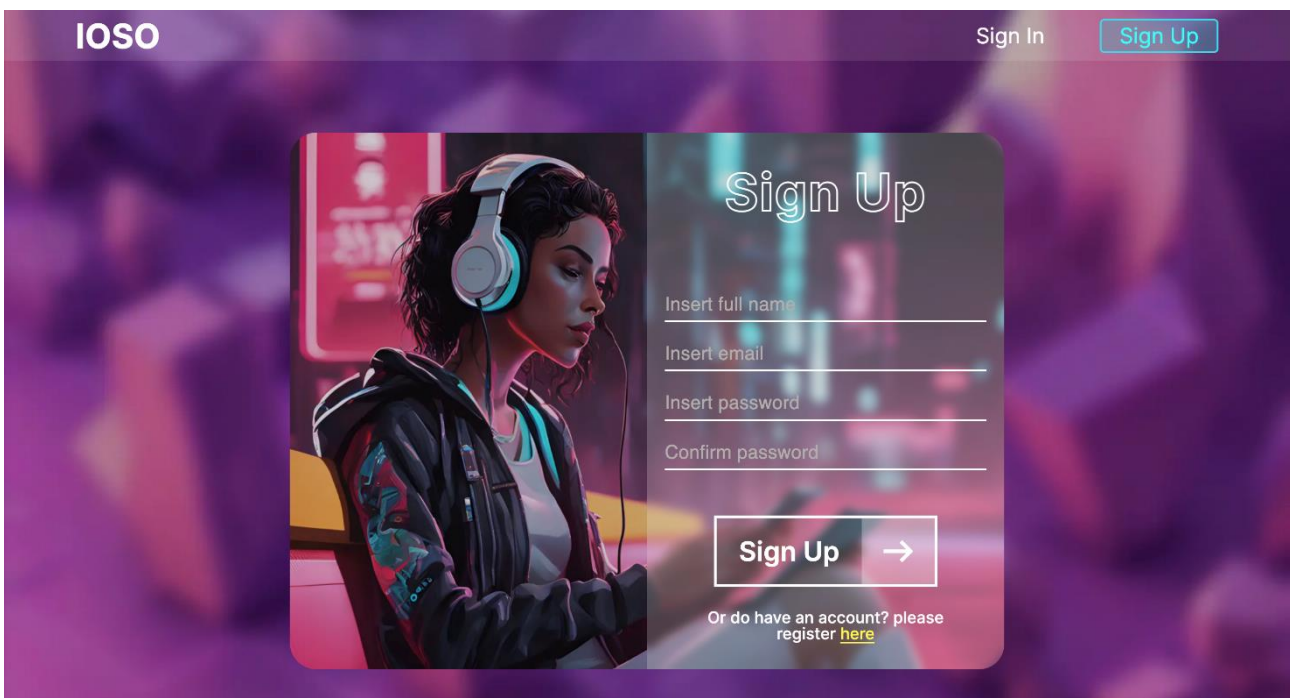


Fig. 4. Registration page

Figure 5 shows the user profile page, which is the central element of the web system's personalized interface. This page provides the user with convenient access to their personal statistics and history of interaction with the platform. At the top of the page, there is a visual chart showing the main indicators of user activity: the number of tests taken, the number of tests created, and the number of groups created. This visual format allows you to quickly assess your progress and learning effectiveness. Below is the “History” section, which provides a detailed history of test completion. Here, the user can view dates, test names, results, and other accompanying data.

Figure 6 shows the user profile page with the “My quizzes & groups” section open, which provides a convenient interface for managing created tests. This section allows the user to view the list of tests they have created, activate and modify them.

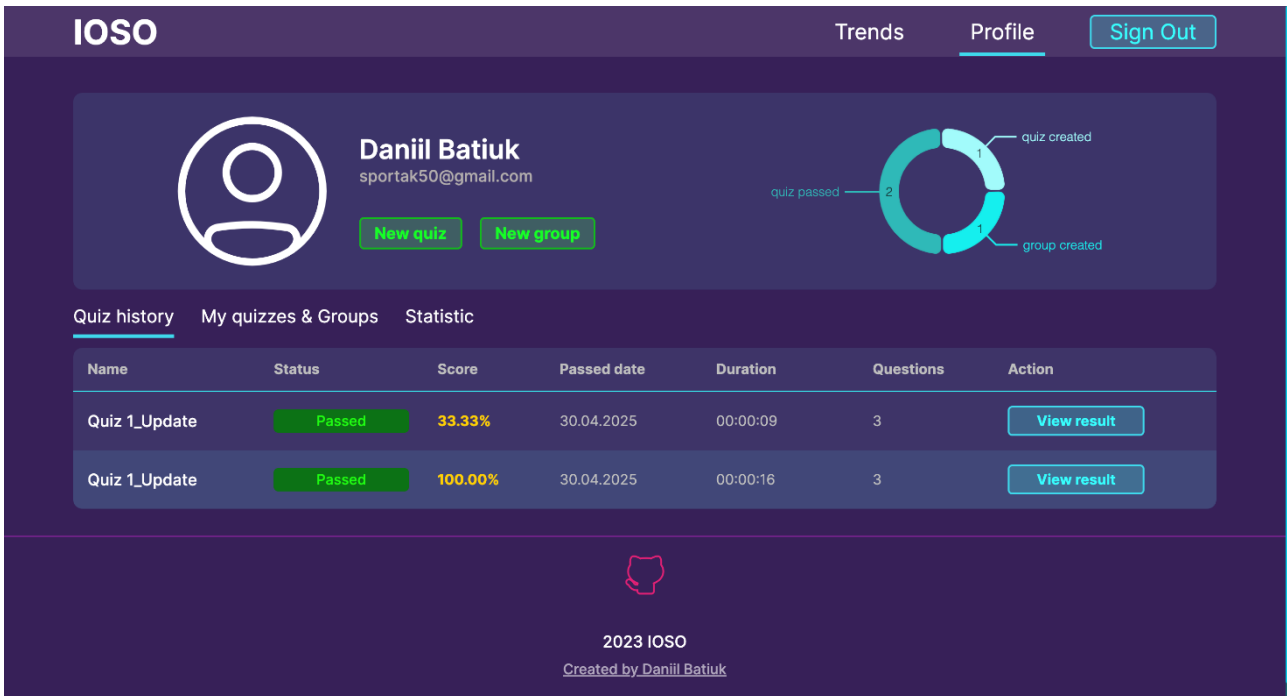


Fig. 5. User profile page with test history

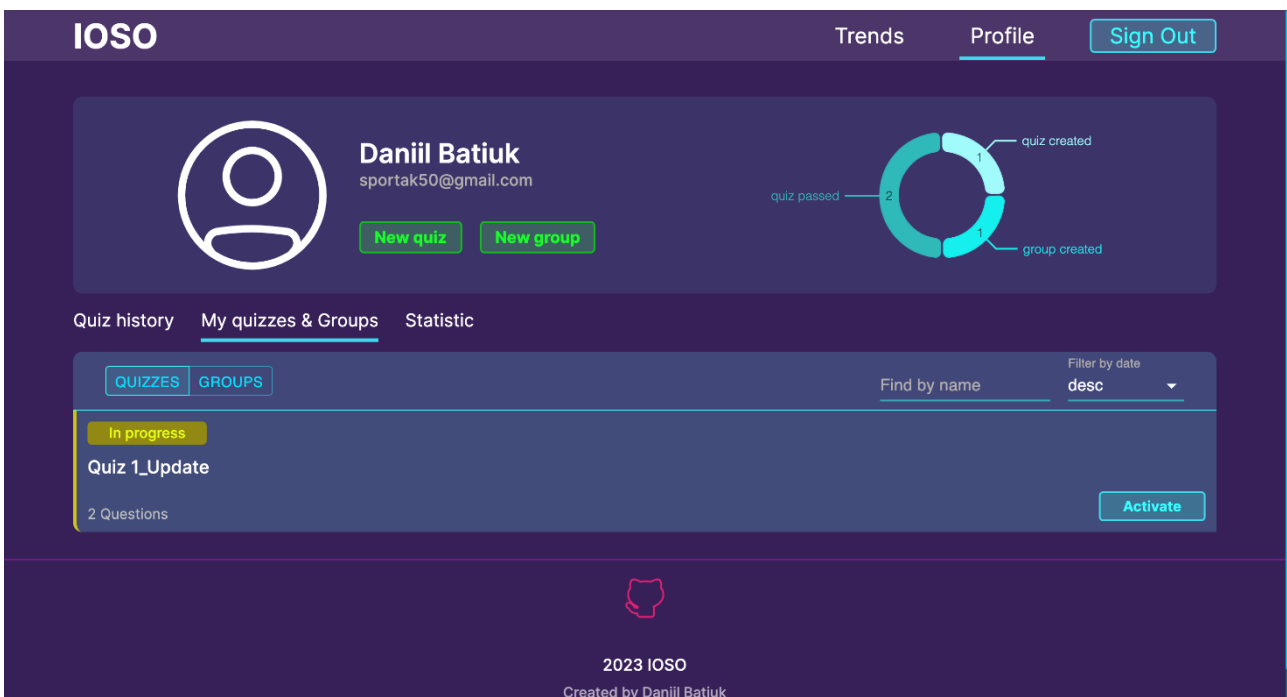


Fig. 6. User profile page with created tests

Figure 7 shows the modal window what gives the user the opportunity to activate the created test. After activation, the test becomes available for other users to take through the current trends page. The window contains basic information about the test and a confirmation that it is ready to be published. This function provides control over the moment of launching the training material.

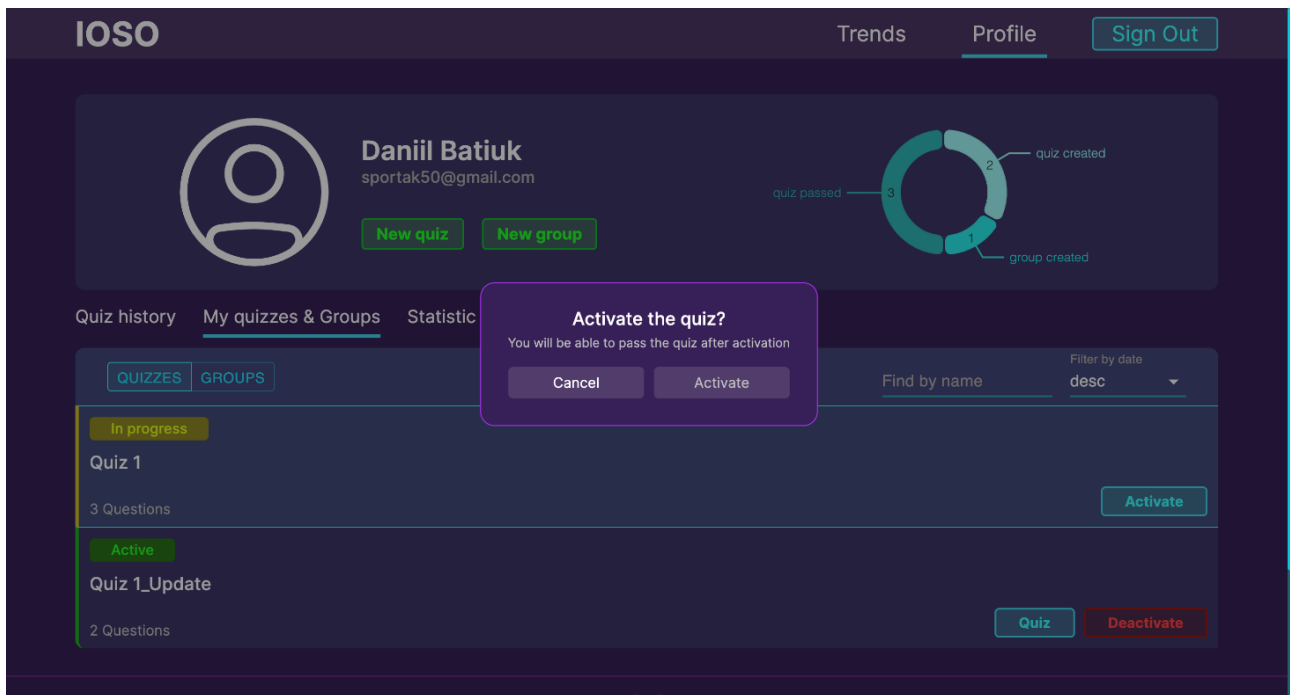


Fig. 7. Modal window for activating the test

Figure 8 shows the user profile page with the “My quizzes & groups” section open and the groups subsection, which allows the user to view the groups they have created. The user's profile page shows a section with the study groups they have created. Here you can view group names, the number of participants, and access settings. The interface allows you to manage each group separately - edit, delete, or open it for new participants. This helps organize the learning process in teams.

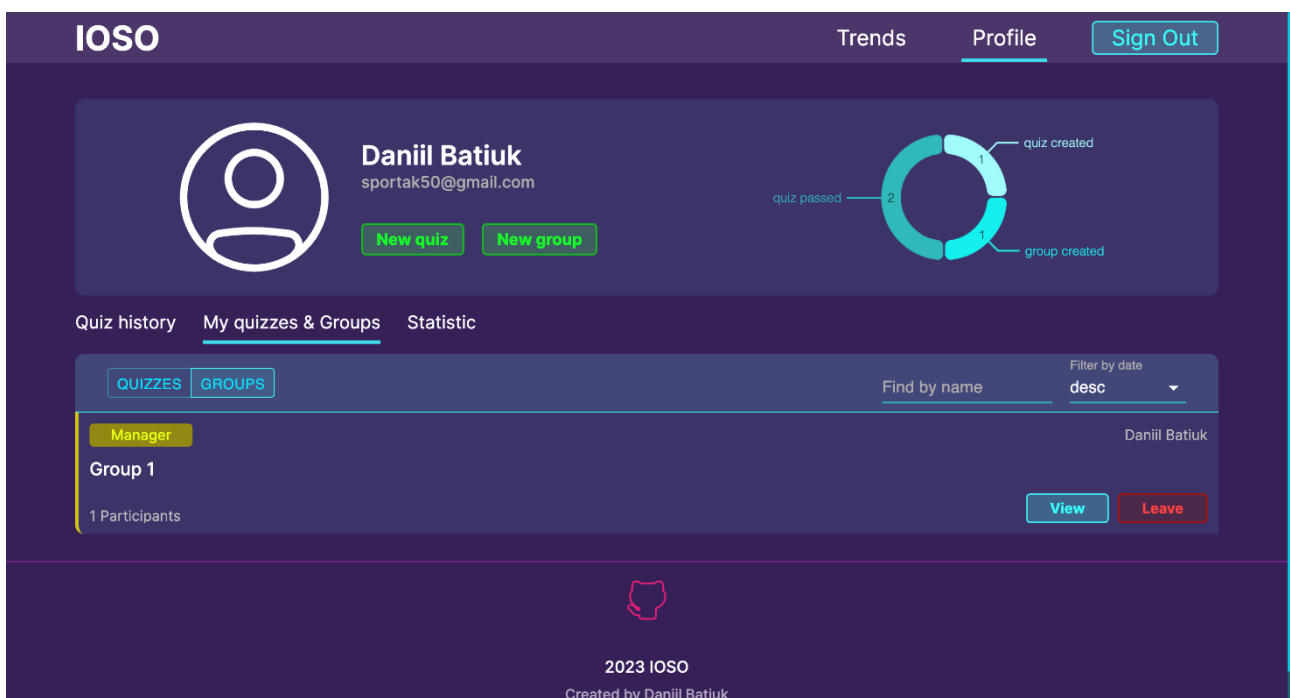


Fig. 8. User profile page with created groups

Figure 9 shows a user profile page with the “Statistics” section open, which allows the user to view statistics on the tests they have created. They can see the number of times the test has been taken, the percentage of the text passed, the average percentage of correct answers, and the average time taken to complete the test. The chart also shows the average number of points received for each question.



Fig. 9. User profile page with statistics

Figure 10 shows the test creation page with the “Basic settings” section open. This is the initial stage of test creation, where the user enters basic information, including the name of the test. The interface is clear and structured, which allows you to quickly move to the next stages of setup. Creating named tests makes it easier to identify and use them later. This ensures easy navigation in the system.

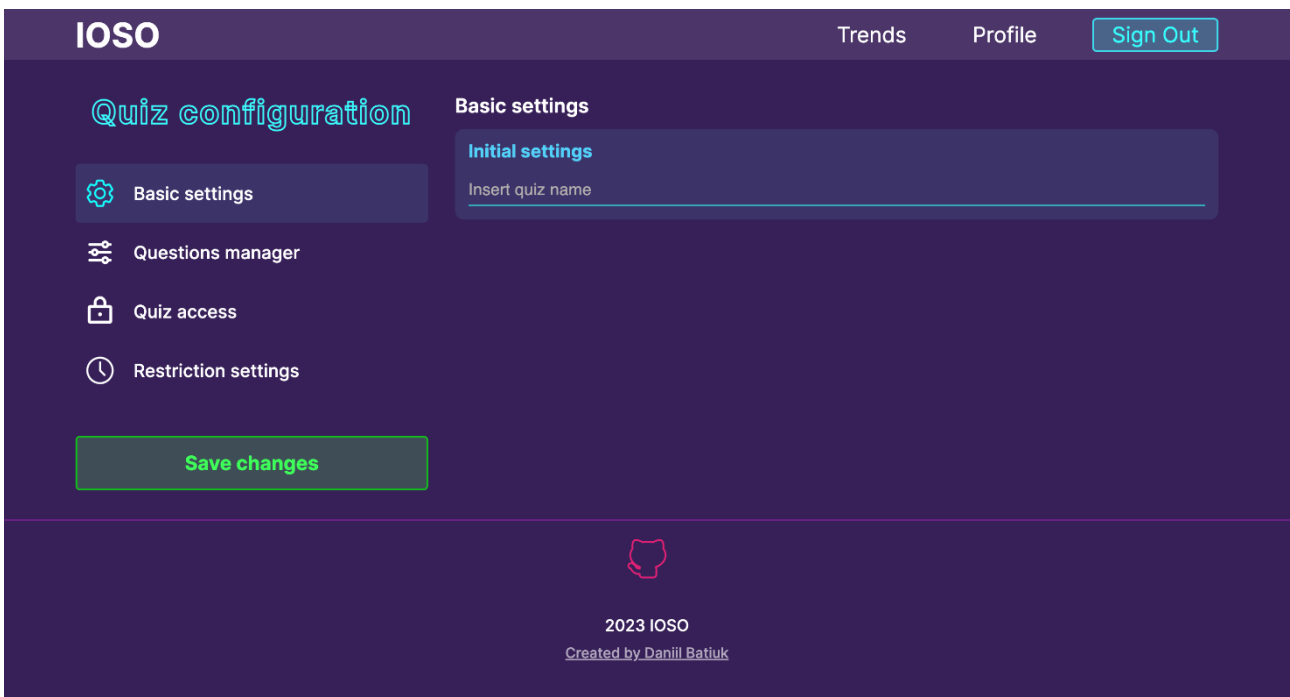


Fig. 10. Test creation page (test name)

Figure 11 shows the test creation page with the “Questions manager” section open. At this stage, the user adds questions to the test, defining the type of each question, wording, answer options, and correct answers. The interface supports flexible editing and viewing of the test structure. This allows you to create adaptive and meaningful mnemonic training exercises. The quality and diversity of the training content is ensured.

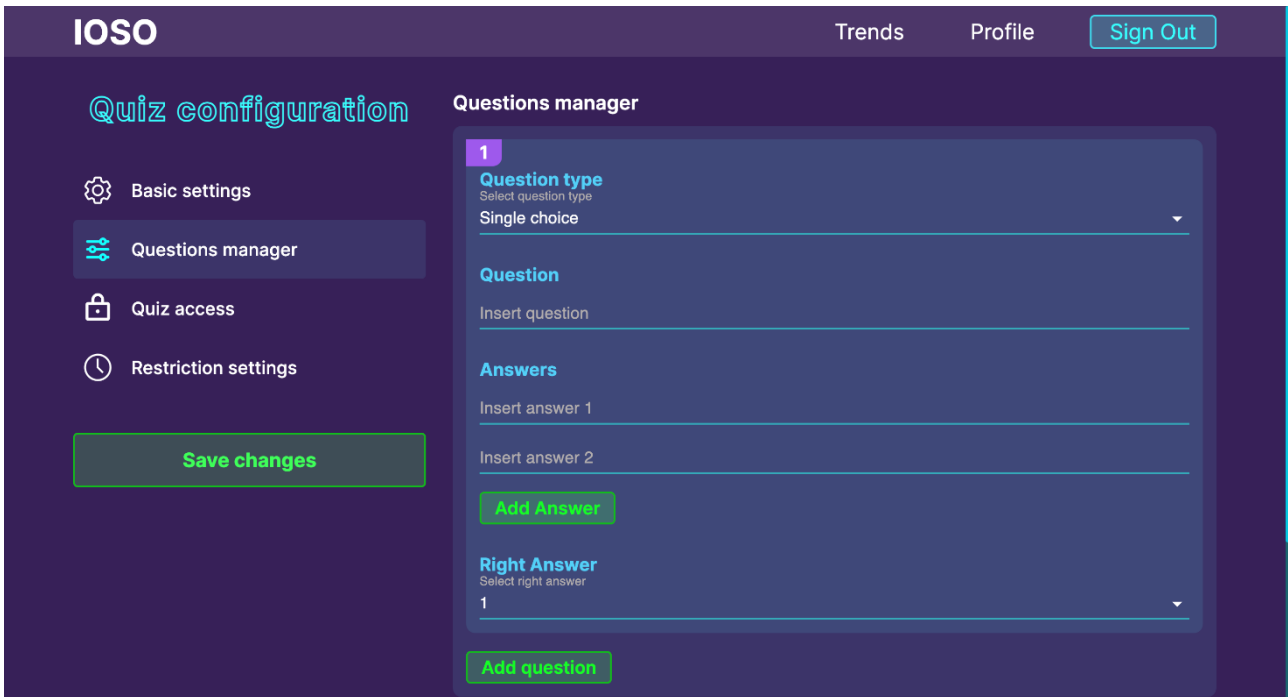


Fig. 11. Test creation page (questions)

Figure 12 shows the test creation page with the “Quiz access” section open. This section allows you to customize access to the created test. Users can make it open to everyone, restrict it to certain groups or individuals. This allows you to more accurately target the learning content to the right audience. Flexibility in access control increases the efficiency of the learning process.

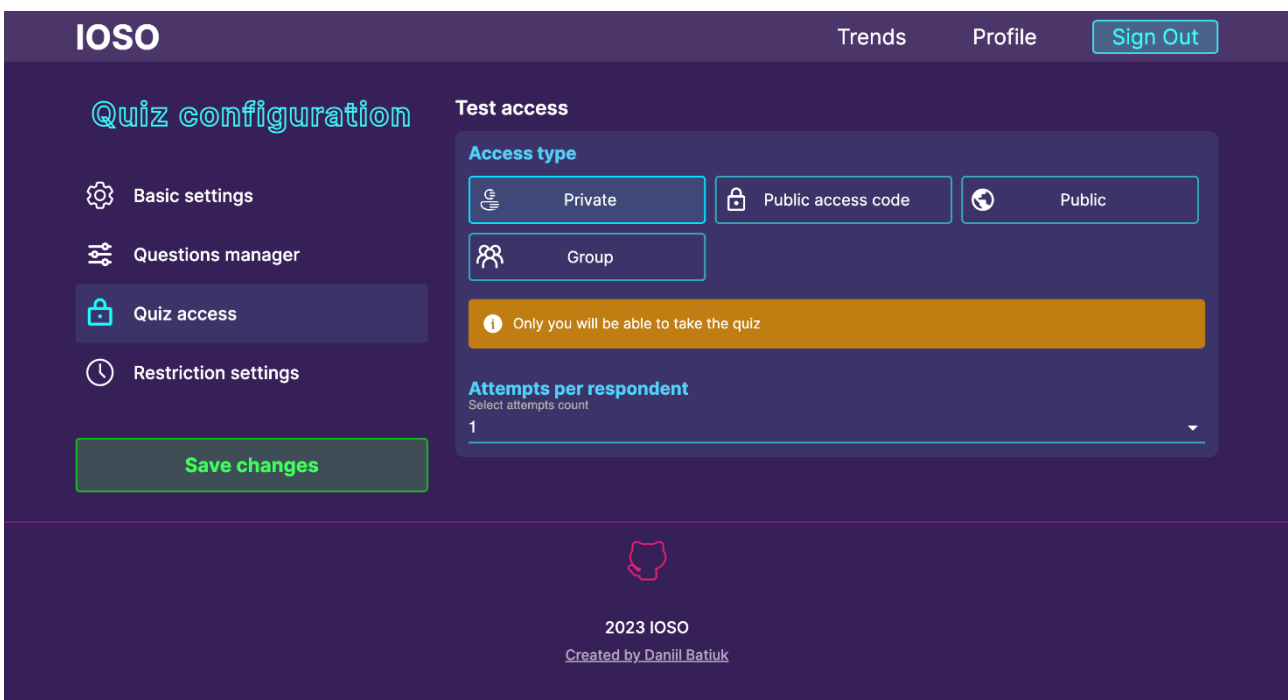


Fig. 12. Test creation page (access to test)

Figure 13 shows the test creation page with the “Restriction settings” section open. On this page, you can set limits on the test: the number of attempts, the duration of the test, and the deadline. This allows you to create conditions that are close to real work situations or training requirements. Such control increases user discipline and assessment accuracy. Restrictions are an important component of the training methodology.

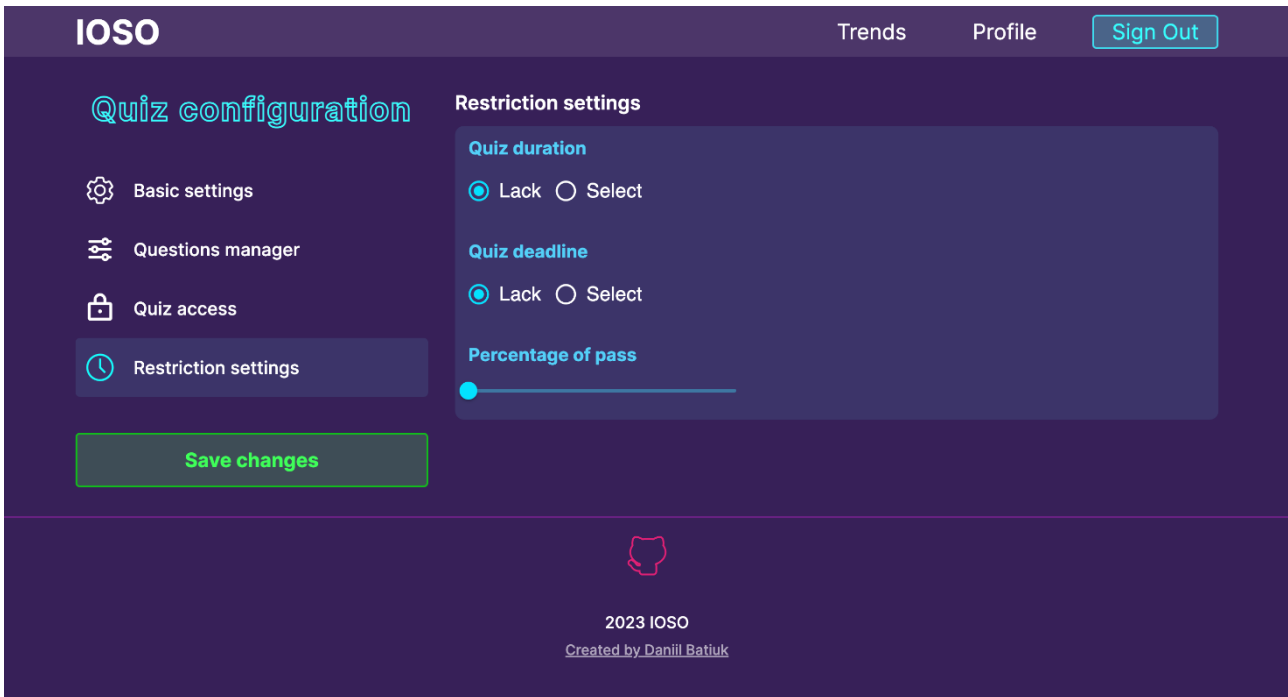


Fig. 13. Test creation page (restrictions)

Figure 14 shows the group creation page with the “Base settings” section open. When creating a group, the user enters its name, which will become an identifier in the system. This stage is the first step in creating a learning environment for the selected audience. A simple interface makes it easy to launch a new group quickly. Creating named groups makes them easier to manage and navigate.

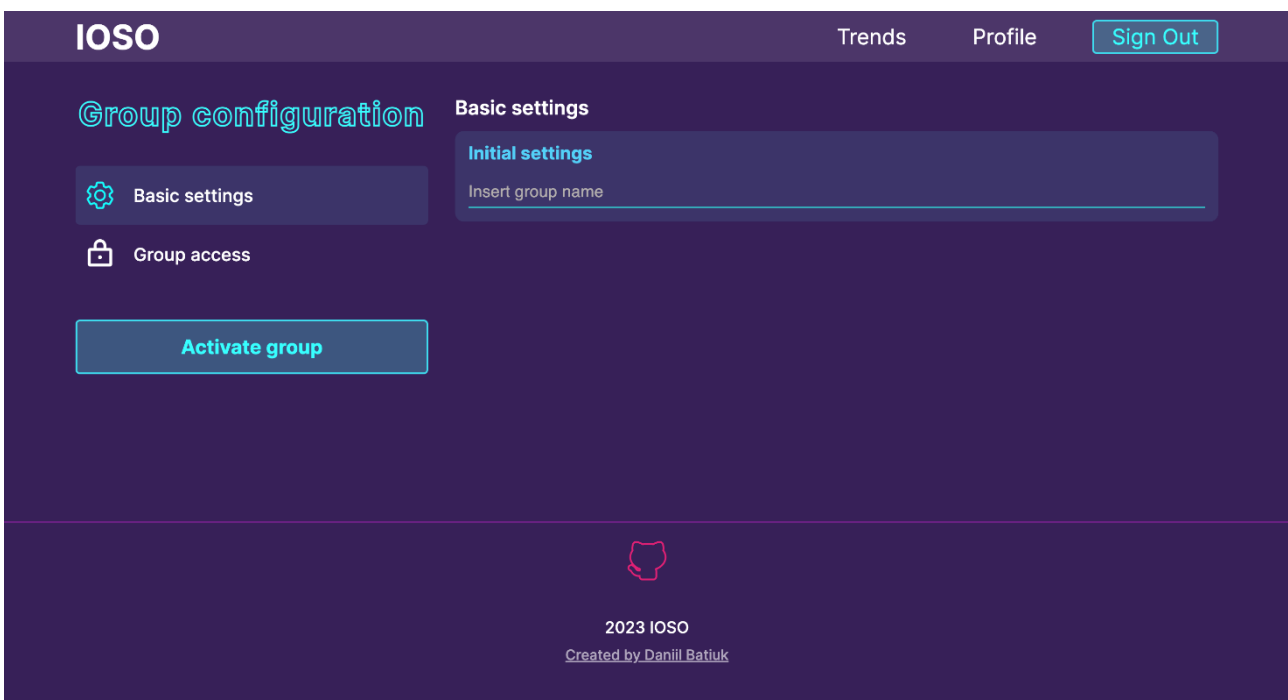


Fig. 14. Group creation page (group name)

Figure 15 shows the group creation page with the “Group access” section open. This interface allows you to define who has access to a study group. The group administrator can select open or restricted access mode, as well as set a join code. This provides flexible management of learning streams. The mechanism allows you to work effectively with both large and narrowly targeted audiences.

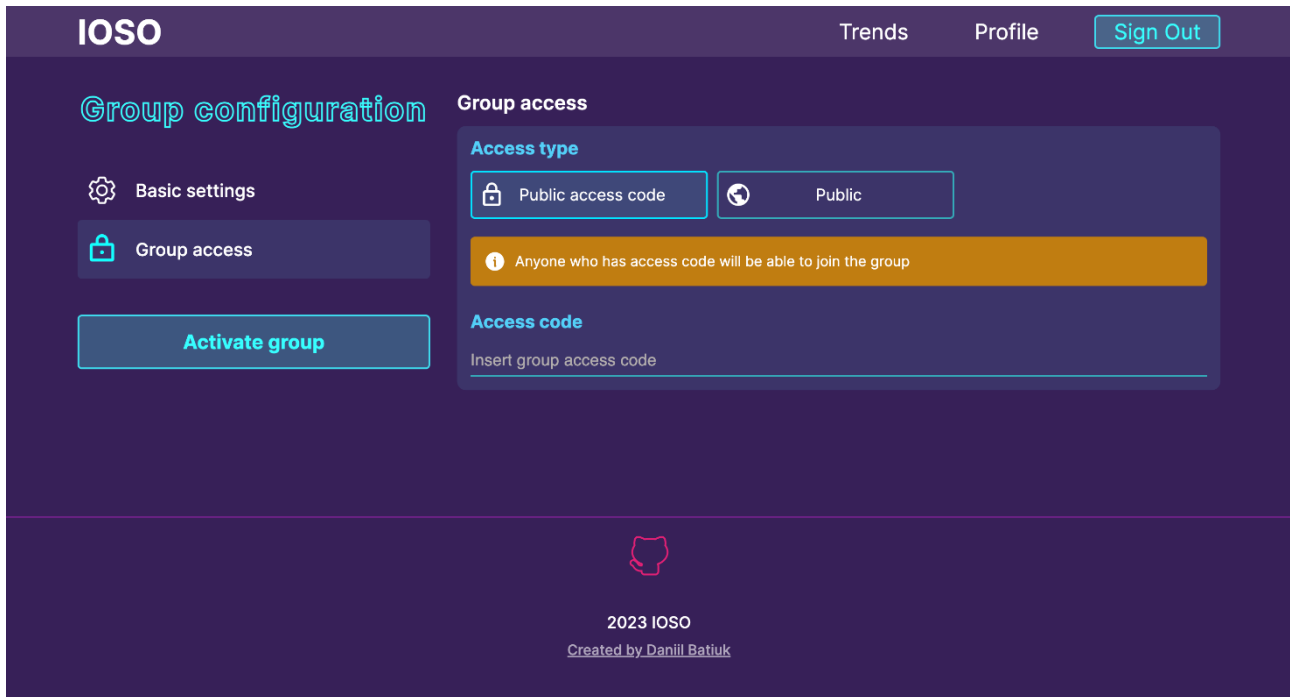


Fig. 15. Group creation page (access to the group)

Figure 16 shows the trend creation page with the “Quizzes” section open, which acts as a catalogue of available tests in the system. The trends page displays all the tests available for taking. Users can see the names of the tests, their popularity, and ratings. This makes it easier to choose the right material for memory training. This page also helps to promote high-quality training courses within the system.

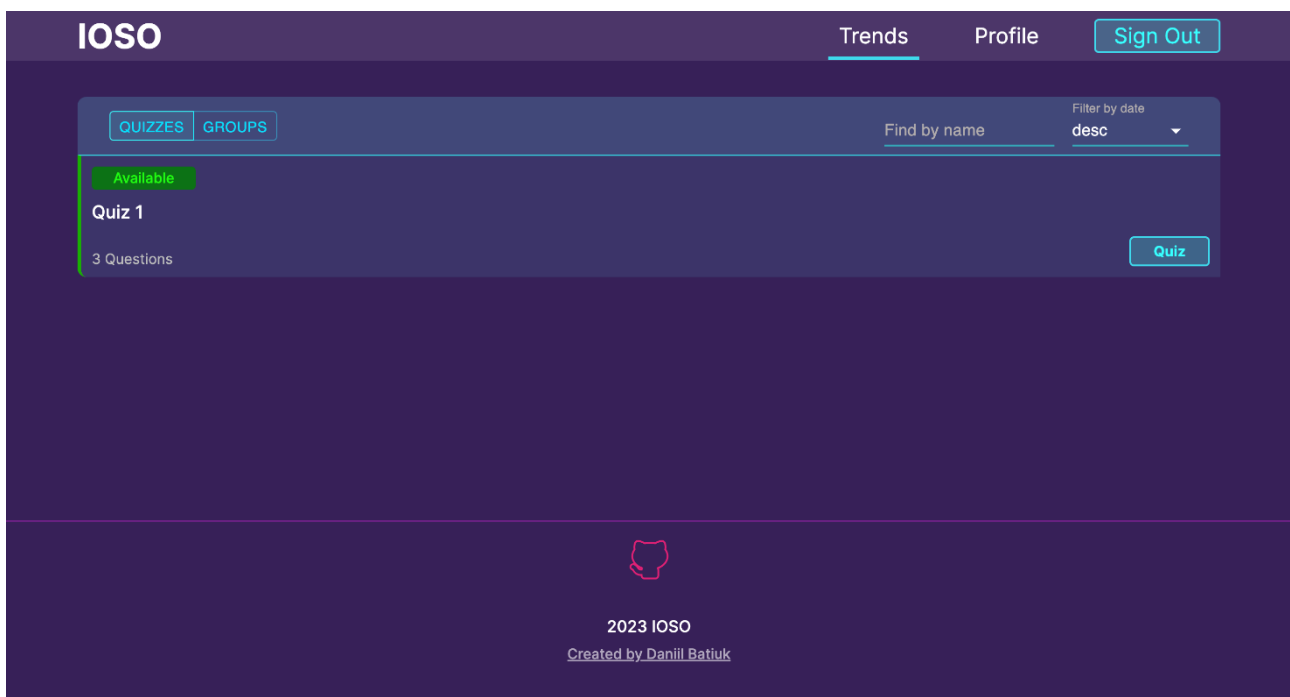


Fig. 16. Trends page with a list of all available tests

Figure 17 shows the modal window confirming the completion of the test. After the test is completed, the user sees a modal window with information about the work done. The window displays the number of attempts made, the duration of the test, and other details. This allows you to immediately evaluate the result and proceed to analyse your own performance. Such feedback is important for motivation and self-control.

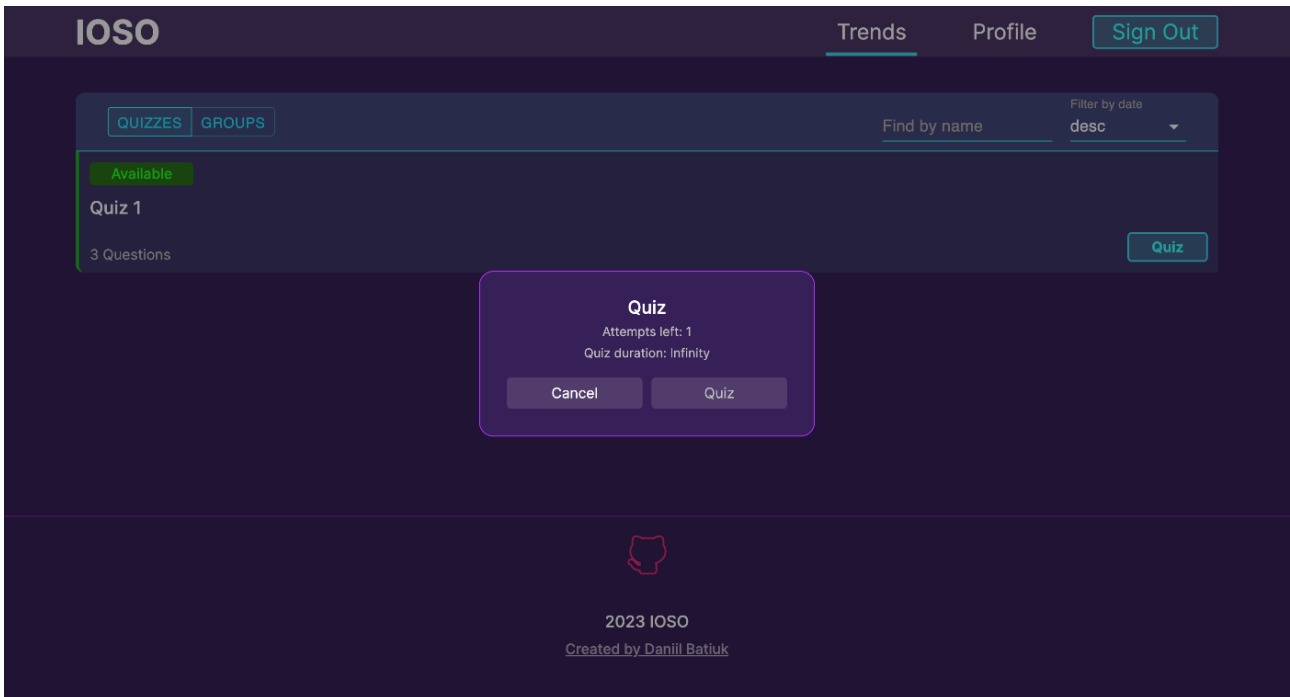


Fig. 17. Modal window confirming test completion

Figure 18 shows the trend creation page with the “Groups” section open, which acts as a catalogue of available groups in the system. This page shows the study groups available for joining. Users can view their names, descriptions, and level of openness. This makes it easy to find a relevant community for learning. The functionality is especially useful in a corporate environment with a large number of groups.

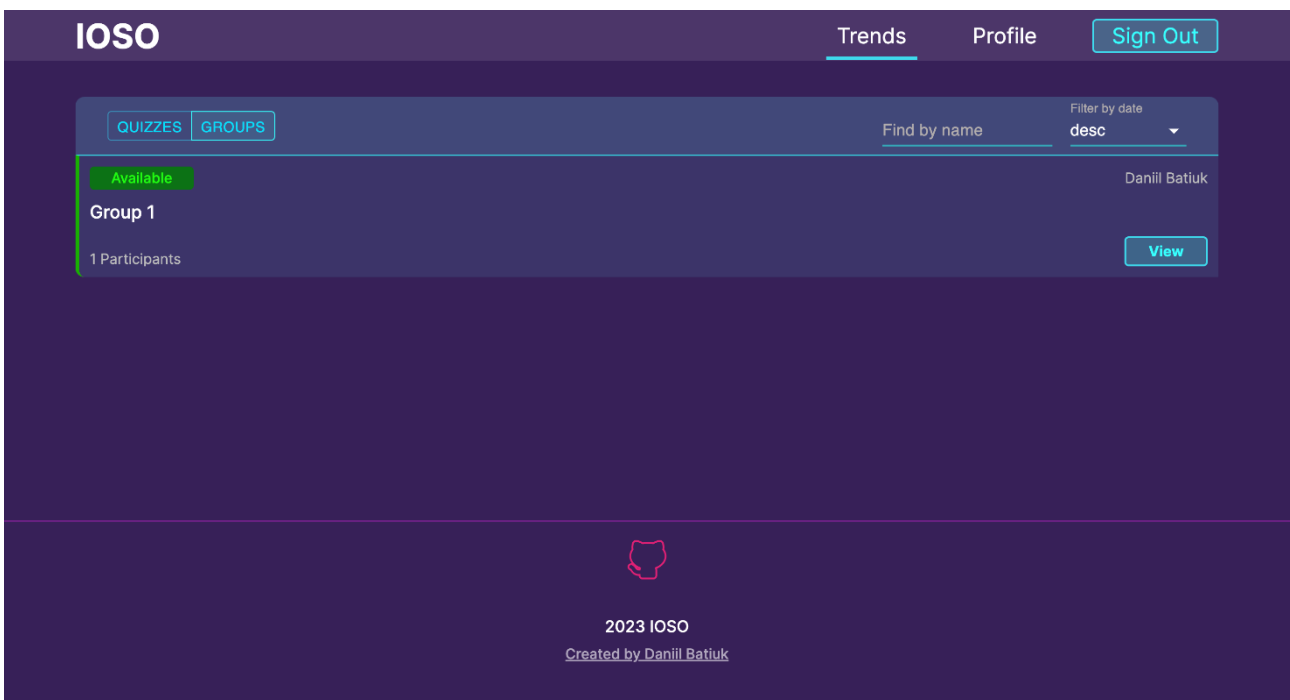


Fig. 18. Trends page with a list of all available groups

Figure 19 shows the group page, where group members can view available tests and general information about users. The page of a particular group displays a list of its members and the tests available for taking. The interface allows you to conveniently manage the learning process within the group. This makes it easier to coordinate and monitor progress. This page is the main workspace for group interaction in the mnemonic training system.

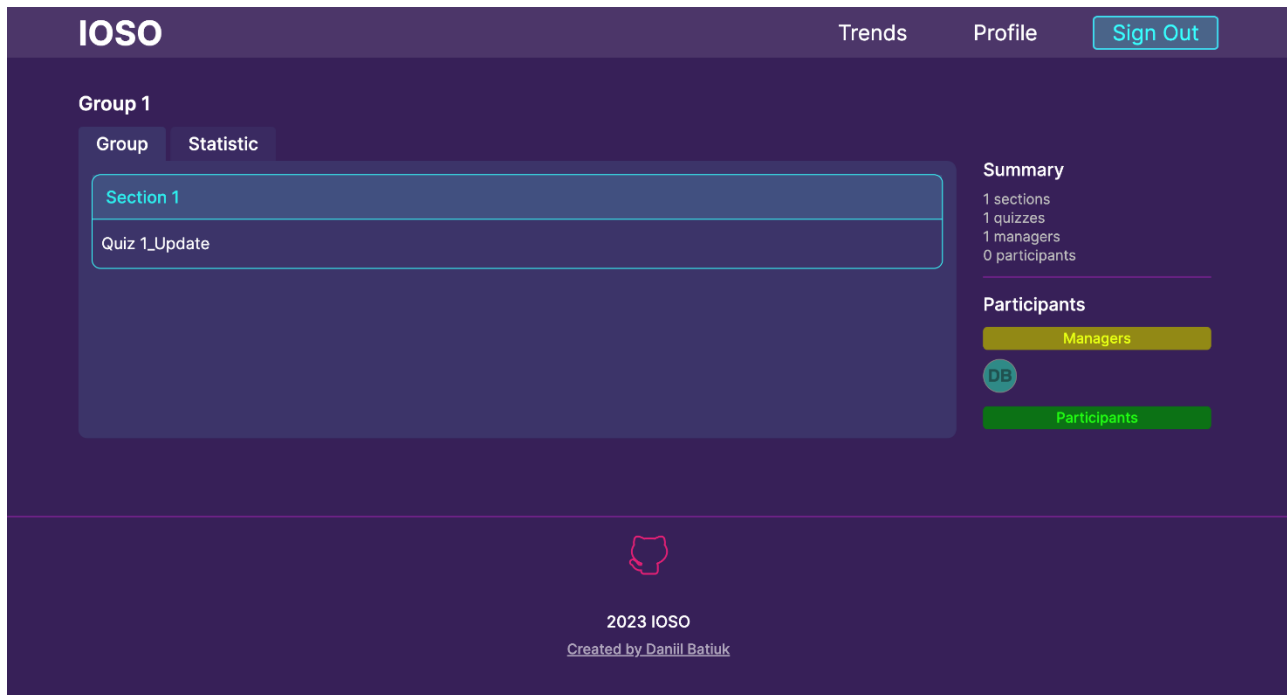


Fig. 19. Group page

IV Discussion

The conducted research highlights the practical significance and potential of integrating mnemonic training into corporate learning environments through web technologies. The developed system addresses several common limitations found in traditional and digital memory training tools. Firstly, it eliminates the need for pre-trained cognitive skills by providing structured, intuitive, and guided exercises. Secondly, the web-based nature of the platform ensures accessibility and scalability, enabling employees to train from any location and at any convenient time. This flexibility aligns with modern hybrid work models and supports continuous professional development.

The use of a modular architecture allows for the implementation of a wide range of training scenarios – from onboarding new employees to improving specialized knowledge retention among experienced staff. Additionally, gamification and personalized analytics foster user motivation and enhance engagement. The system collects detailed statistics on learning outcomes, which can be used to tailor learning trajectories and improve content quality.

One of the key advantages of this system lies in its ability to integrate mnemonic methods such as the method of loci, visual associations, acronyms, and spaced repetition into an interactive environment. This not only boosts memory retention but also stimulates neuroplasticity and supports long-term cognitive development, as confirmed by recent neuroscience studies.

However, it is important to note that the quality and effectiveness of the mnemonic materials used in training remain critical to achieving desired outcomes. While the system provides the technological foundation and delivery mechanisms, further research is needed to explore optimal combinations of mnemonic techniques for different categories of learners and types of information. In future work, integration with AI-based content generation, adaptive difficulty adjustment, and AR/VR support may significantly expand the capabilities and impact of the system.

V Conclusion

The results of this research confirm the feasibility and effectiveness of using a web-based information system for mnemonic training in the context of professional development. The developed platform combines the classical principles of mnemonics with modern technological solutions, providing users with a flexible and personalized environment for memory training. The system architecture enables tracking progress, managing access, and analysing results, which are critical for maintaining learning efficiency and ensuring consistent knowledge retention in corporate settings.

By focusing on business employees, the system directly addresses real-world needs such as fast onboarding, reduced human error, and improved customer service quality. The inclusion of group-based learning modules, custom test creation, and performance analytics makes the platform adaptable to various industry-specific scenarios. Moreover, its user-friendly interface and the possibility of gradual integration into existing learning workflows enhance its practical value and ease of adoption.

The study contributes to the growing field of technology-enhanced learning, particularly in the application of cognitive science to enterprise training systems. It demonstrates that memory development, which has traditionally been addressed through individual and manual techniques, can now be effectively systematized and scaled. The proposed system lays a strong foundation for future development, including integration with artificial intelligence, mobile platforms, and immersive learning environments.

In conclusion, this project provides a solid basis for organizations seeking to improve staff competencies through scientifically grounded, digital mnemonic training tools. Its modularity and adaptability ensure its relevance in diverse training contexts, while the research opens pathways for further innovation in cognitive-oriented educational technologies.

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