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EDUCATIONAL EFFECTIVENESS OF MATHEMATICS E-LEARNING WITH A UNIFIED MATH INPUT USER INTERFACE

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ABSTRACT

Recently, science, technology, engineering, and mathematics (STEM) education has become increasingly important, and one of the challenges in digitizing mathematics teaching materials is the input of formulae. To address this issue, we proposed an intelligent formula input user interface (UI) employing predictive conversion from ambiguous text in 2015. In mathematics education that uses an e-learning environment, UI unification is important for inputting mathematical formulae. In this study, we adopted the mathematics e-learning system Moodle+STACK to unify the UI for inputting the mathematical formulae. The effectiveness of this method in mathematics education was verified in a mathematics class for students at our university and student reactions were investigated.

KEYWORDS

Mathematics E-Learning, Equation Input Interface, Learning Support Environment, Unified UI

1. INTRODUCTION

Owing to the increased importance of science, technology, engineering, and mathematics (STEM) education in recent years, the difficulty of inputting formulae has emerged as a challenge in digitizing mathematics teaching materials (Smith and Ferguson, 2005).

To address this issue, we proposed a user interface (UI) system, MathTOUCH, which employs artificial intelligence (AI) for predictive conversion of ambiguous strings into input formulae in 2015. In 2017, we implemented MathTOUCH in answer format for teaching assessment using a computer algebra kernel, STACK (Sangwin, 2013), which is an online testing system that allows users to respond directly to mathematical expressions. In 2019, we proposed a mathematical graph maker that uses natural descriptions to draw graphs from functions entered using MathTOUCH, and in 2023, we proposed the MathTOUCH editor as a rich-text editor plugin for Moodle (Moodle, 2025), a learning management system (LMS) that includes mathematical formulae.

In this study, we adopted Moodle+STACK, a mathematics e-learning system, to unify the UI for inputting mathematical formulae using MathTOUCH, and verified its effectiveness in mathematics education. We used MathTOUCH in a mathematics class for second-year undergraduate students at our school, and investigated their reactions. We established that their responses were positive.

2. RELATED WORKS

Here, we discuss the proposed mathematical input UI for STEM education and the various online support tools that apply it.

2.1 MathTOUCH: Challenge of Math Input Issues

In 2015, we (Fukui and Shirai, 2015) proposed MathTOUCH, an intelligent formula input interface that compensates for ambiguous human instructions to reduce the burden of inputting the formulae required to create mathematics teaching materials. MathTOUCH allows the user to enter desired mathematical expressions using artificial intelligence (AI) (Fukui and Shirai 2017) and predicts candidates from ambiguous character strings. Our evaluation results indicate that math input is 1.2–1.7 times faster than conventional input methods, and that user satisfaction is high.

Figure 1 shows a screenshot of a sample obtained from MathTOUCH. A desired mathematical formula is constructed by first inputting a linear string of characters from the keyboard or touchpad, followed by selecting the desired candidate from a sequence of predicted candidates, and finally fixing it by pressing the Enter button. The linear string rule for mathematical expressions in MathTOUCH linearly sets the key letters (or words) corresponding to the elements of a mathematical expression in the order of colloquial (or reading) style without considering two-dimensional placement and delimiters. For example, the case of “1 over a squared plus 3” is shown in the second line of Table 1. Figure 1 shows a screenshot taken after inputting the linear string and presenting the predictive conversion candidates. The desired mathematical expression, $\frac{1}{a^2+3}$, is displayed as the first candidate in the candidate list marked ② in Figure 1. Notably, the linear string entered in ① is ambiguous regarding the part that corresponds to the denominator. List ② presents candidates that are predictable from the same linear string, ordered by possibility.

If users attempt to enter a long expression and the desired formula is not included in the candidate list, pressing the [Refine] button allows them to narrow the conversion to only partial expressions. By repeating this partial fixing operation, users can reliably construct the desired mathematical formula. Moreover, these fixing operations are designed to update machine learning data that determines priority for the next predictive conversion.

The third and fourth lines in Table 1 present comparative examples of computer algebra system (CAS) commands and LaTeX, respectively. These commands and grammar enable the mechanical construction of mathematical expressions, requiring users to input them correctly according to the specifications of the machine. Thus, the advantage of MathTOUCH lies in its ability to compensate for ambiguous human input and construct mathematical expressions.

Through machine learning experiments using 4,000 mathematical expressions from high school mathematics texts as instructional data, we observed our predictive algorithm for linear string conversion to the N-best candidate mathematical formulae, with an accuracy of 85.2% for the top-ten ranking, by improving upon a previously proposed structured perceptron algorithm for application to general mathematics categories. The mean CPU time for predicting each mathematical expression with the corresponding linear string of length less than 16 was 2.84 s.

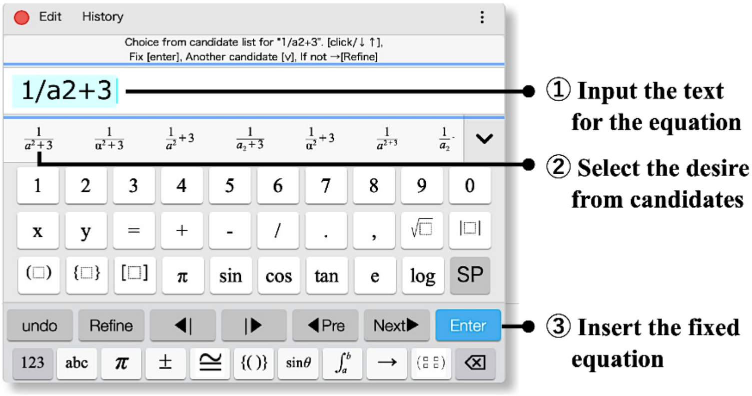

Figure 1. Screenshot of MathTOUCH and input operation steps

Table 1. Example of the linear string in the case of "1 over a squared plus 3"

Rules	Example in the case $\frac{1}{a^2+3}$
Linear string in MathTOUCH	**1/a2+3**
CAS command (Maxima)	**1/(a^2+3)**
LaTeX	**\frac{1}{a^2+3}**

2.2 Mathematics E-Assessment System Using MathTOUCH

In 2014 (Shirai and Fukui, 2014), we implemented MathTOUCH in an equation-answer format in STACK, an e-assessment system for mathematics. In our eight-week learning investigation (Shirai and Fukui, 2017), we observed that students could practice using MathTOUCH at the same learning rate as when using the current interface. Furthermore, the questionnaire results revealed a significantly higher level of satisfaction with memorability when using MathTOUCH than when using the current interface.

2.3 Rich-Text Editor for Math e-Learning Using MathTOUCH

The standard text editor on Moodle requires input in the LaTeX text format, which is inconvenient for users unfamiliar with the LaTeX syntax. Therefore, we developed a rich-text editor using MathTOUCH and implemented it as a Moodle plug-in to reduce the burden of mathematical inputs (Shirai et al., 2018). Figure 2 shows a sample screenshot of the rich-text editor, whose features are summarized as follows.

- Mathematical expressions can be constructed using WYSIWYG.
- The proposed editor can seamlessly switch between the editor and MathTOUCH UI.
- The math input interface enables users to enter mathematical documents using a keyboard.
- The math input interface allows users to enter mathematical expressions with a low workload.
- This editor enables users to convert selected parts of mathematical documents into LaTeX format.

Our evaluation enabled users to input mathematical documents approximately 1.5 times faster than the standard UI, with high subjective satisfaction (Shirai et al., 2023).

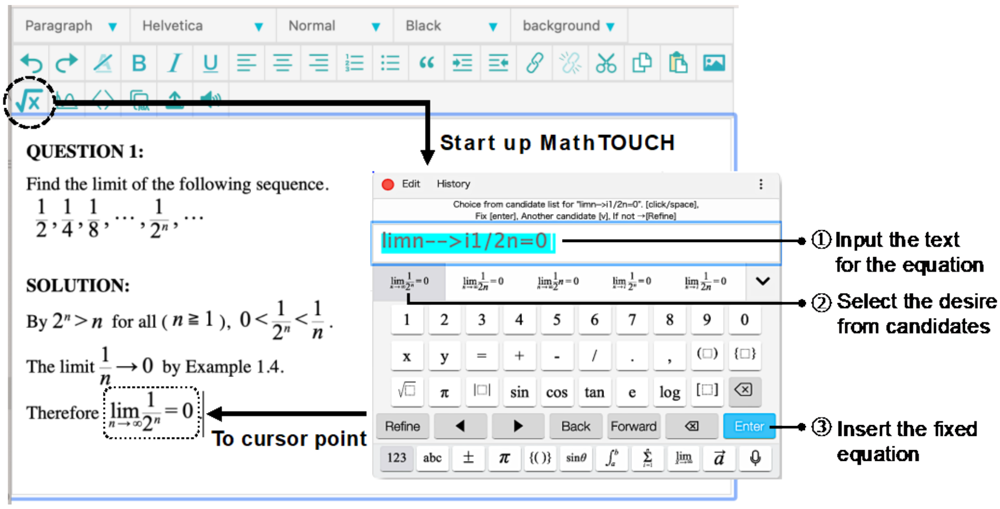

Figure 2. Screenshot of the rich-text editor using MathTOUCH

2.4 Graph Maker using MathTOUCH

In 2019, we (Endo et al., 2019; Fukui, 2019) applied MathTOUCH to propose a graph maker as a tool for online support in creating teaching materials for STEM education. Figure 3 shows a screenshot of a sample GraphMaker (MathTOUCH Graph), whose features are summarized as follows.

- MathTOUCH facilitates the editing of graph equations.
- Equation labels can be clearly displayed on the canvas.
- Numerical values such as coordinates can also be expressed as formulae that include $\sqrt{\ }$ or π.
- Drawing command scripts for graph elements is easy to understand, as in mathematics textbooks.
- Graphs can be exported to various types of outputs.

The results of a user study with 62 students showed that the system usability scale was 61.7%, and their subjective satisfaction with learning through the graph-maker was greater than that through classroom learning, with 82% of students reporting that it was easy to understand (Fukui, 2020).

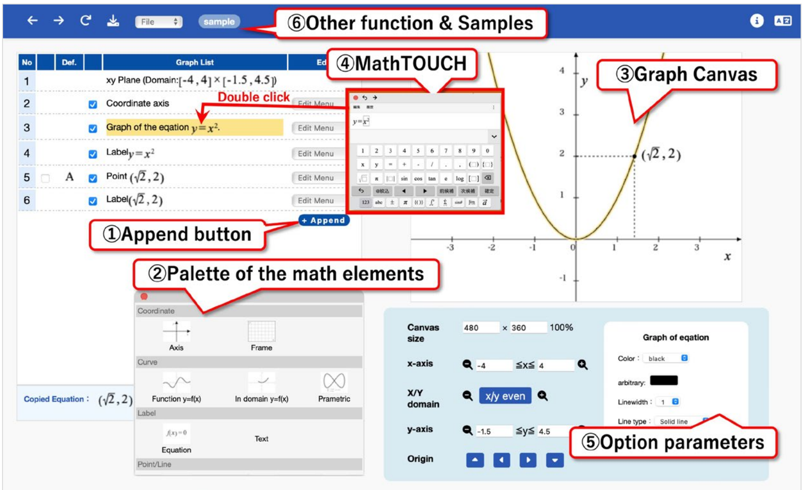

Figure 3. Screenshot of the GraphMaker using MathTOUCH

3. MATHEMATICS E-LEARNING SYSTEM UNIFIED UI

To integrate the results of our previous research and utilize them in an actual mathematics class, we constructed a learning support environment for mathematics e-learning using a unified math UI, MathTOUCH.

3.1 Learning Support Framework

The framework showing the flow of the teaching material data is shown in Figure 4. Specifically, we adopted Moodle as an LMS, implemented the aforementioned mathematics e-assessment system STACK plug-in, and assigned a rich-text editor using MathTOUCH as the standard editor for Moodle to create a mathematics e-learning environment linked to the MathTOUCH Graph. This environment has the following important features.

- The MathTOUCH UI allows the input of common quiz expressions, algebraic calculations, and function graphs, as well as creating math notes and submitting questions.
- Reusability such as copying and re-editing formulae from Mathematical quiz texts and notes.
- Math document accessibility with smooth collaboration between the editor and graph maker.
- Portability that enables loading and saving in LaTeX format. Therefore, numerous external mathematics materials are available in LaTeX.

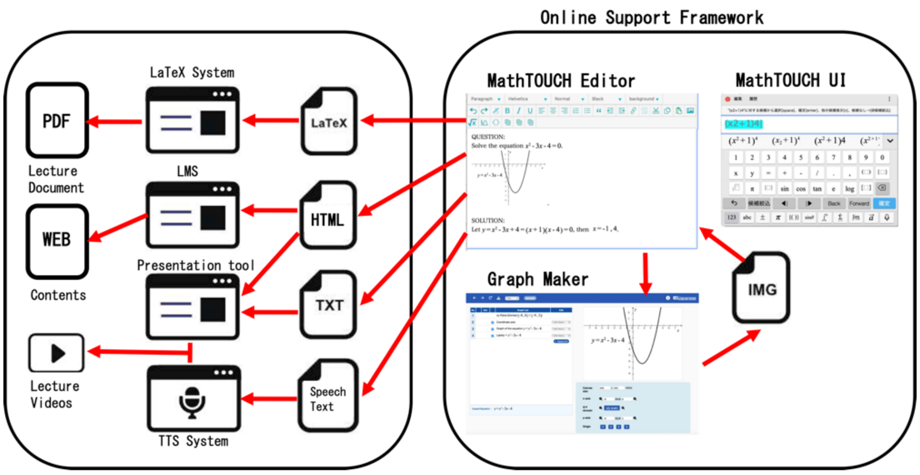

Figure 4. Online support framework for math learning

3.2 Activity and Resource

The activities and resources prepared for the Moodle course in the practical class (Figure 5) are explained in the next section. The four educational activities served four functions: 1. Mathematical chat (MathChat), 2. Forum, 3. Quiz, and 4. Assignment. MathChat allows students to ask questions during class using MathTOUCH. The forum function allows students to contact each other and ask questions outside the class. The quiz function allows students to complete various practice quizzes online at any time. The assignment function allows students to solve mathematical problems through rich text and graphical submission. Course resources included PDF files of course text, links to lecture videos on YouTube, URLs to websites containing MathTOUCH graphs, and sample programs related to the class.

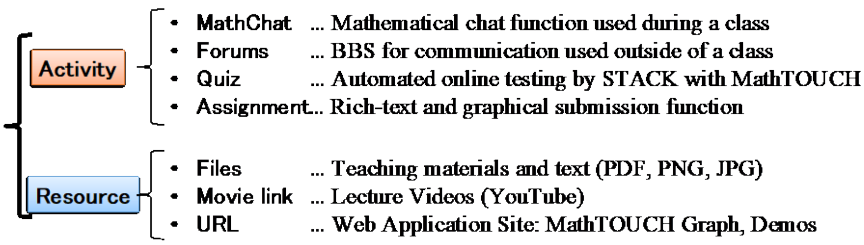

Figure 5. Activities and resources in the Moodle+STACK system using MathTOUCH

4. EVALUATION OF MATH CLASS EDUCATION

This mathematics e-learning system was introduced using a unified UI (MathTOUCH) to allow the input of mathematical formulae into my mathematics class, and its acceptance by students and effectiveness in mathematics education was further verified.

4.1 Course Contents and Class Status

The proposed system was used in 90-min lectures over a 15-week period, with 39 second-year university students studying IT, AI, and data science. Students used their own laptops and took the course through LMS. None of the participants had any experience in using Moodle or MathTOUCH before taking this course. In the first lecture, approximately 30 min were spent instructing students on how to use MathTOUCH, allowing them to practice taking online tests. From the second lecture onwards, they could operate the system on their own.

The course introduced calculus and linear algebra, which served as the mathematical foundation for learning statistics and data science. The primary learning parameters are listed in Table 2.

We investigated the prior knowledge of the subjects in terms of their learning levels of "High School Mathematics I, II, and III" in the Japanese curriculum (MEXT, 2025). The results showed that 19%, 56%, and 25% were at levels I, II, and III, respectively. In particular, Level I students were learning calculus for the first time, and all students were new to matrix calculations.

Table 2. Content of the course using the proposed mathematics e-learning system

Chap.	Learning title	Sec.	Main topics
1	**Basic mathematics notes for informatics**	1.1-1.2	Objectives and calculating formulae
2	**Functions and variations**	2.1-2.3	Exponential and logarithmic functions
3	**Differential calculus and its applications**	3.1-3.7	Derivatives, Newton method, indefinite integral
4	**Vector**	4.1-4.4	Components, inner product, and spatial shapes
5	**Differentiation of functions of multiple variables**	5.1-5.2	Partial differentiation and gradient vector
6	**Matrix**	6.1-6.3	Inverse matrix and linear transformation

4.2 Educational Activities

In the experimental lessons, the teaching materials and educational activities implemented using mathematics e-learning were as follows.

4.2.1 MathChat and Forums

Although the MathChat function was not used frequently, there were questions in some chat sessions about the meaning of mathematical expressions and the definitions of vector symbols. Students received feedback on their mistakes using MathChat. The forum function was also used to communicate weekly assignments and questions to students outside the class. To help improve the system, students also reported bugs in the MathTOUCH editor through a forum.

4.2.2 Quiz

We prepared 195 STACK-type questions with mathematical solutions, divided into 27 tests using a quiz function that students could study repeatedly. Each test consisted of two to ten questions, and the answers were entered into MathTOUCH. The test was performed within a time limit of 10–30 min. The test results were automatically graded immediately after the test. Test takers could take the test multiple times within a one-week period, and the highest score was considered. However, the test was designed to randomly generate homogeneous questions, resulting in different questions for each examinee. Each time the same examinee took the same test, different questions were presented.

4.2.3 Assignment

The assignments in our course were mathematics problems designed to check the students' comprehension of textbook learning items, as shown in Table 2. Approximately one or two questions among the 24 questions were answered weekly. Students answered questions by submitting online reports that included mathematical expressions and graphs using the rich -text editor. Manual grading was performed. MathTOUCH was used to input the mathematical expressions and create graphs. An example of an assignment question and the actual student answers are shown in Figure 6. The questions were delivered in PDF format using LaTeX, and the students submitted their answers online using the MathTOUCH editor.

An example of Assignments

[**Exercise 4.7**]

When $\boldsymbol{p} = \begin{pmatrix} 2 \\ -1 \\ -1 \end{pmatrix}$, $\boldsymbol{q} = \begin{pmatrix} -4 \\ 2 \\ 0 \end{pmatrix}$, $\boldsymbol{r} = \begin{pmatrix} r_1 \\ r_2 \\ r_3 \end{pmatrix}$,

find $\boldsymbol{r}$ such that $\boldsymbol{p} \perp \boldsymbol{r}, \boldsymbol{q} \perp \boldsymbol{r}, |\boldsymbol{r}| = 1$.

A student's answer of [Exercise 4.7]

Since $\boldsymbol{p} \perp \boldsymbol{r}$, $\boldsymbol{p} \cdot \boldsymbol{r} = 2r_1 - r_2 - r_3 = 0. \quad \cdots \ (1)$

Since $\boldsymbol{q} \perp \boldsymbol{r}$, $\boldsymbol{q} \cdot \boldsymbol{r} = -4r_1 + 2r_2 = 0. \quad \cdots \ (2)$

Since $|\boldsymbol{r}| = \sqrt{{r_1}^2 + {r_2}^2 + {r_3}^2} = 1$, ${r_1}^2 + {r_2}^2 + {r_3}^2 = 1. \quad \cdots \ (3)$

From equation (2), $r_2 = 2r_1$,

Hence, substtuting this into equation (1), $2r_1 - 2r_1 - r_3 = 0$,

then $r_3 = 0$.

Substituting these into equation (3), we get ${r_1}^2 + (2r_1)^2 = 5{r_1}^2 = 1$

which means ${r_1}^2 = \frac{1}{5}$.

Solving this, we get $r_1 = \pm\frac{1}{\sqrt{5}}$.

Therefore, the desired vector is

$\boldsymbol{r} = \begin{pmatrix} \pm\frac{1}{\sqrt{5}} \\ \pm\frac{2}{\sqrt{5}} \\ 0 \end{pmatrix}$ (where the compound order is the same).

Figure 6. Examples of assignment questions and student answers

4.3 Evaluation

To verify the educational effectiveness of the educational activities conducted in the mathematics e-learning environment described above, we analyzed the quiz and assignment scores and investigated subjective satisfaction with the class.

4.3.1 Result of Online Test (Quiz)

The results of the quizzes conducted over 15 weeks are presented in Table 3. Columns 1–7 of Table 3 show the quiz number, week, text section, study item, number of examinees N (< enrollment 39), number of questions, and time limit (minutes) for each quiz. Columns 8–10 of Table 3 show the results for each quiz (excluding those who had not attempted the quiz) in terms of the average time to answer as a percentage of the time limit, average number of attempts, and the average score (out of 10 points), where the value in parentheses for each average represents its standard deviation. These results indicate that the average number of attempts for all 27 quizzes was 2.52 (SD 0.73) attempts (min: 1.6, max: 4.4) and the overall average score (out of 10) was 8.37 (SD 0.6) points (min 7.18, max: 9.50).

This means that more than half of the students attempted to repeat the exam more than 2.5 times until they obtained a score of 7.18 or higher.

However, there were six quizzes with an average number of attempts of three or more and ten quizzes with an answer time rate of 70% or higher; therefore, the time limits for some of the tests need to be improved, depending on the difficulty of the questions.

Table 3. Results of quizzes over 15 weeks

No.	Week	Sec.	Learning Item	N	No. of quiz	Time limit (min)	Average answer time rate	Average no. of attempts	Average score
1	1	1.2	**Integers, fractions, and decimals**	38	9	20	74 (18)%	3.4 (2.0)	8.55 (2.15)
2	1	1.2	**Expanding and factoring polynomials**	38	10	20	68 (17)%	1.7 (0.9)	9.50 (0.86)
3	1	1.2	**Square root calculation**	38	5	12	57 (18)%	2.3 (1.8)	9.05 (2.01)
4	2	2.1	**Calculating fractional expressions**	36	5	12	73 (21)%	3.2 (2.5)	8.67 (2.34)
5	3	2.1	**Calculation of irrational expressions**	38	5	12	76 (23)%	4.0 (3.1)	8.11 (2.67)
6	3	2.2	**Exponential expression**	38	10	18	51 (27)%	2.7 (1.9)	8.55 (2.37)
7	3	2.2	**Exponential calculation**	38	10	18	72 (22)%	2.7 (3.1)	8.34 (2.35)
8	3	2.2	**Exponential law**	36	5	15	80 (17)%	2.7 (1.9)	7.78 (2.65)
9	4	2.3	**Logarithmic Representation**	38	10	15	55 (21)%	2.2 (2.9)	8.97 (1.73)
10	4	2.3	**Logarithmic Laws**	38	5	12	70 (23)%	2.2 (1.6)	7.84 (2.69)
11	4	2.3	**Logarithm base conversion**	36	5	12	60 (25)%	2.0 (1.3)	8.17 (2.31)
12	5	3.1	**Limit value**	35	10	15	49 (21)%	2.4 (1.7)	9.06 (1.59)
13	5	3.1	**Infinity limit**	34	10	20	54 (24)%	4.4 (2.6)	7.18 (2.18)
14	6	3.2	**General formula for derivatives**	32	10	10	73 (18)%	3.3 (1.5)	8.13 (2.95)
15	6	3.2	**Calculating derivatives**	33	10	20	68 (21)%	2.7 (2.0)	7.64 (1.76)
16	7	3.3	**Tangents and Normals**	36	2	5	67 (22)%	3.8 (3.3)	9.44 (1.59)
17	8	3.3	**Indefinite Integral**	33	5	10	72 (21)%	2.5 (1.8)	8.67 (1.38)
18	9	4.1	**Inner product of vectors**	35	4	20	40 (21)%	1.7 (1.1)	8.51 (3.02)
19	10	4.2	**Vector equation of a line**	37	4	20	44 (22)%	2.1 (1.4)	8.89 (2.20)
20	10	4.2	**Vector equation of a plane**	37	2	12	47 (26)%	1.7 (1.3)	8.78 (2.98)
21	11	5	**Calculating partial derivatives**	35	10	20	68 (20)%	2.1 (1.3)	8.14 (1.63)
22	12	6.1	**Matrix operations**	33	10	20	86 (17)%	2.6 (1.7)	8.21 (2.25)
23	12	6.1	**Matrix product**	33	10	15	78 (19)%	1.9 (1.2)	8.39 (2.03)
24	12	6.1	**Matrix representation of simultaneous equations**	32	10	18	79 (17)%	2.1 (1.4)	7.35 (2.49)
25	13	6.2	**Determinants and inverse matrices**	31	4	15	65 (21)%	2.5 (1.9)	7.61 (2.16)
26	14	6.3	**Various matrices and linear transformations**	34	10	25	60 (24)%	1.6 (1.2)	8.68 (2.52)
27	15	6.3	**Space Vector Rotation**	23	5	30	57 (26)%	1.7 (0.9)	8.00 (2.15)

4.3.2 Result of Online Assignment

In this class, in addition to the above calculation exercises using the auto-grading quiz, students were given report assignments almost every week in which they had to answer a math problem to check their understanding of the week's study items. Assignments were submitted in the form of a report document created in the MathTOUCH editor (Figure 6) or solution graph data created in the MathTOUCH Graph within one week and were scored manually on a 10-point scale.

The results of the evaluation of mathematics report assignments over the 15-week period are summarized in Table 4. Columns 1–5 of Table 4 represent the assignment number, week, text section, study item, and submission format (Doc: math document and/or Graph: graphical answer) for each assignment. The sixth column of Table 4 shows the number of assignment submissions (examinees N) and the seventh column shows the average score (with SD) of the scoring results for all submissions for each assignment.

These results indicate that the average score (out of 10) for all 24 assignments was 7.96 (SD 2.13) (min: 4.94, max: 9.37). However, only the average score for assignment No. 15 was below the lower inner-quartile boundary point, although it was not an outlier. The results of the average and standard deviation of the assignment evaluations, excluding assignment No. 15, indicate that the assignments were generally appropriate.

Table 4. Results of assignments over 15 weeks

No.	Week	Sec.	Learning Item	Submission format	N	Average score	(SD)
1	2	2.1	**Vertex of a quadratic function**	Graph	37	7.35	(1.93)
2			**Drawing function curves**	Graph	36	8.50	(1.58)
3	3	2.1	**Inverse function**	Doc. & Graph	37	7.97	(2.15)
4		2.2	**Exponential function curves**	Graph	36	8.42	(2.17)
5	4	2.3	**Logarithmic Order Calculation**	Doc. & Graph	34	8.68	(1.74)
6			**Exponential and logarithmic problems**	Doc.	35	7.40	(1.97)
7	5	3.1	**Limits including infinity**	Doc.	31	6.74	(1.83)
8	6	3.2	**Derivatives of the Normal Distribution**	Doc. & Graph	31	8.65	(2.11)
9	7	3.2	**Differentiation of an Inverse Function**	Doc.	35	9.37	(1.73)
10		3.3	**Tangent and normal equations**	Doc. & Graph	34	9.09	(1.44)
11			**Function increase and decrease**	Doc. & Graph	34	9.24	(1.65)
12			**Approximation solution by Newton's method**	Doc. & Graph	32	7.63	(2.65)
13			**Approximation solution by Newton's method**	Doc. & Graph	32	8.69	(1.86)
14	8	3.4	**Speed and acceleration of moving point**	Doc. & Graph	33	8.33	(2.17)
15			**Indefinite integral**	Doc.	34	4.94	(3.08)
16	9	4.1	**Vector operations**	Graph	36	7.72	(2.28)
17			**Vector sum (commutative law/associative law)**	Graph	21	7.95	(2.29)
18	10	4.2	**Calculation by vector components**	Doc.	36	7.11	(2.49)
19			**Perpendicular conditions of space vector**	Doc.	32	8.22	(2.14)
20	11	5.1	**Partial Differentiation**	Doc.	32	8.06	(2.60)
21		5.2	**Tangent plane equation**	Doc.	29	6.69	(2.21)
22	13	6.1	**Inverse matrices and simultaneous equations**	Doc.	31	8.10	(2.09)
23		6.2	**Matrix solution of simultaneous equations**	Doc. & Graph	29	9.10	(2.43)
24	15	6.3	**Linear transformation matrix**	Doc.	24	7.08	(2.60)

4.3.3 Analysis of Results

Two of the 39 students who enrolled retired during the course; therefore, the study results will be analyzed for the 37 students who were evaluated. Figure 7 shows a scatterplot of the average scores between the quizzes and assignments (calculated from 100 points) for the 37 students. In grading the students' scores, unsubmitted quizzes or assignments were calculated as 0 points, in contrast to the average score calculation for quizzes and assignments in the previous subsection. The average score for all students across all quizzes was 78.4 (SD 18.5) points, and the average number of times they attempted the same quiz was 2.52 (SD 0.73). The average score for all students on all assignments was 69.5 (SD 20.0) points.

There was a strong correlation (coefficient of determination, R2 = 0.74) between each student's quiz and assignment scores. These results suggest that students who practiced the quiz well also scored highly on the assignments, and the high average scores in the class suggest that the educational objectives were generally achieved.

4.3.4 Result of Subjective Satisfaction

Finally, students' subjective satisfaction with the class and the proposed learning environment was investigated using a 12-question questionnaire (rated on a five-point scale ranging from negative to positive). Figure 8 presents a radar chart of the average results for each question between Q1-Q12 (Table 5). The main comments on the question "What's the good thing about the class study or e-learning system?" are shown in Table 6. The comments on the question "What's wrong with the class study or e-learning system?" are shown in Table 7. The overall evaluation showed that the class was conducted without any problems. In particular, the high evaluation of Q10 indicated that students were very satisfied with the new knowledge and skills taught in class. In fact, according to comments from the students, the good thing about online tests was that the system allowed them to immediately check their answers, and they could take the tests at any time. Approximately 70% of the students said that this learning environment was easier to understand than classroom learning.

In the comments in Table 7, there are four detailed suggestions for teaching methods and textbooks that require further consideration. The issue of No. 4 in Table 7 is a bug in the system, which has improved over time. However, there are several issues with short time limits for the online test, indicated by No. 1 in Table 7, that need to be considered. This will be discussed in the following subsections.

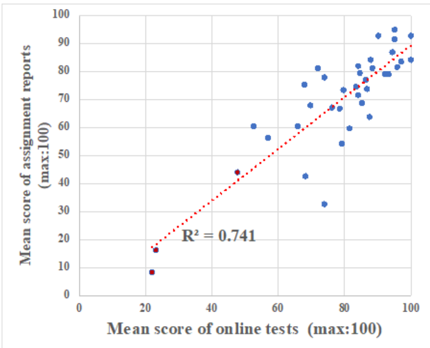

Figure 7. Scatter plot of quizzes and assignment scores

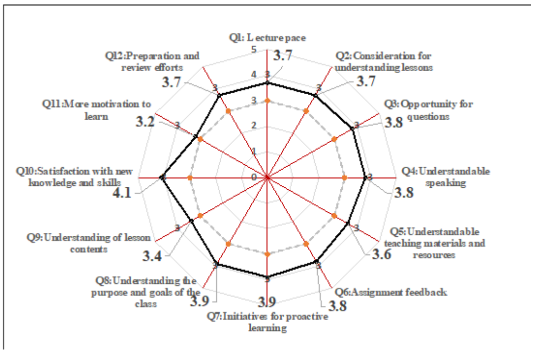

Figure 8. Radar chart of the results for each question

Table 5. Twelve-question questionnaire on mathematics classes

No.	Questions of questionnaire (1. Strongly disagree, 2. Disagree, 3. Neither, 4. Agree, 5. Strongly agree)
Q1	**Was the pace of the class good?**
Q2	**Was the content of the classes clear and organized?**
Q3	**Did the teacher give you enough opportunity to ask questions or exchange opinions?**
Q4	**Were the teacher's explanations and word choices clear?**
Q5	**Were the textbooks and class materials easy to understand and helpful for learning?**
Q6	**Did the teacher give you feedback on the assignments or the work submitted?**
Q7	**Did the teacher provide you with various ideas that helped you learn independently?**
Q8	**Did you learn and understand the objective and the goal of this class?**
Q9	**Did you clearly understand the contents of the class?**
Q10	**Did you learn new information and skills?**
Q11	**Would you want to learn more about the contents of this class?**
Q12	**How much time per week did you spend for class preparation and review, including out of class studying with friends?**

Table 6. Comments on good thing about the class study or e-learning system

No.	Comments on question "What's the good thing about the class study or e-learning system?"
G1	We can check our answers immediately using this (online testing) system.
G2	We can study (quizzes/assignments) whenever we want.
G3	We can input mathematical expressions digitally and view them clearly (with MathTOUCH).
G4	We can select and input difficult mathematical symbols from candidates (with MathTOUCH).
G5	We can rewrite formulas many times (with MathTOUCH).
G6	We can draw graphs neatly (with MathTOUCH Graph).
G7	The distributed teaching materials are very clear and easy to understand.
G8	It's great that we can not only attend math lectures but also solve problems and submit assignments using the MathTOUCH math e-learning system.
G9	We prefer graphing tools and sample calculation programs that are easy to use, and tasks that involve solving problems using them.
G10	I think I've become better at solving math problems since before taking this course.

Table 7. Comments on wrong point about the class study or e-learning system

No.	Comments on question "What's wrong with the class study or e-learning system?"
W1	Some questions had short time limits, so be retried. (5 people agree)
W2	For some formulas in the text, it would be helpful to have the intermediate steps.
W3	If teachers ask students to answer questions during class, I think more students would participate actively.
W4	MathTOUCH sometimes malfunctions, making it difficult to use.
W5	There were parts where the explanation differed slightly from the math I learned in high school, making it difficult to understand.
W6	Sometimes the example problems explained in class differ from the homework assignments.

4.4 Discussion

Here, we discuss the points revealed by the evaluation results, organized by topic.

4.4.1 Mathematics e-Learning System

Comments from the students (Table 6) indicated that the unified math input UI, MathTOUCH, enabled them to create graphs and solve math problems using the editor, leading to a deeper understanding. Therefore, the math e-learning system was well-received. In particular, learning through quizzes and tests using the STACK e-assessment system was well-received because students could review at home, take the tests at their own pace, and retake them as many times as needed. This indicated that the system was effective.

However, as shown in Table 7, it is difficult to use MathTOUCH. This was because during the first half of the course period, bugs caused malfunctions in the MathTOUCH editor. This error was resolved twice in the study.

4.4.2 Class and Course Materials

The results of the five-point scale evaluation for the 12 questions in Table 5 regarding the class showed averages ranging from 3.5 to 4.1, indicating that the class proceeded smoothly overall. Comments in Table 6 include opinions such as "The text is easy to read and understand" and "The sample programs are easy to work with," indicating that the course contents were also well-received.

However, as shown in Table 7, some students expressed dissatisfaction that the text's explanations and assignments were not of the same quality as the example problems. Therefore, minor improvements were required in the wording and explanatory approaches of the text.

4.4.3 Time Limits of Quizzes

Here, we discuss the online test questions that have shorter time limits, as indicated by No. 1 in Table 7.

We examined three indicators in Columns 8 through 10 of Table 3 related to the factors affecting the answer time: (i) the average answer time rate relative to the time limit, (ii) average number of attempts, and (iii) average score. Students who score below perfect on a test should retake it repeatedly if they feel that their understanding is insufficient.

Analysis of the original data on answer time rates regarding (i) revealed that when the average answer time rate exceeded 70%, nearly five or more students had their answer terminated owing to time limits, suggesting that the time limit may be too short. Regarding (ii), compared to the overall average of 2.5 attempts, an average of three or more attempts was considered a significant burden. Our data analysis revealed that for attempts with an SD of 2.5

or higher, multiple students attempted to retry the exam eight or more times. Regarding indicator (iii), we evaluated quizzes whose average score was lower than the overall average score of approximately eight points. However, because even the quiz with the lowest average score still achieved a high 7.18 points, we considered the difficulty level of the questions to be acceptable.

None of the 27 quizzes exceeded the benchmark for any of the three indicators; however, those exceeding the benchmark for indicator (i) included Nos. 1, 4, 5, 7, 8, 10, 14, 17, 22, 23, and 24. These quizzes may require adjustments to the time limits. Additionally, quizzes No. 13 and 16, which have an average attempt count of 3.8 or higher, are too burdensome and should be reviewed.

However, because the time required for mathematical expression input may have contributed to the shorter time limits observed in the 13 quizzes mentioned above, further consideration beyond revising the time limits is necessary. We plan to address these issues in future studies and reexamine the results.

5. CONCLUSION

In mathematics education that utilizes an LMS, UI unification is important for inputting mathematical formulae. This unification could reduce the burden of LMS operations, allowing teachers and students to focus on teaching and learning, respectively. In this study, we developed a mathematics e-learning system (Moodle+STACK) with a unified equation-input UI, MathTOUCH. The effectiveness of this learning environment was investigated in a mathematics class. First, using a questionnaire, we evaluated the (1) results of automatically graded online tests, (2) grading results of assignment reports submitted online, and (3) results of subjective satisfaction with classes. In (1), the average score was 8.37 (SD 0.6) points (out of 10), which is very high, and the average number of times the students attempted the tests was 2.52 times, which shows that their efforts were effective. Although there were some inappropriate questions, such as setting a time limit, almost no complaints from the students regarding the testing operations in the survey were recorded (3). Although online test exercises are useful for improving calculation skills such as formulae, they are insufficient for testing the abilities of students to document and apply what they have learned. This should be evaluated using assignment tests. In (2), the average score was 7.96 (SD = 2.13) points (out of 10), which is a good result. However, the tests varied, with only the outlier question on the indefinite integral of the velocity scoring 4.94 points, which was outside the interquartile range. This was because approximately half of the students did not understand how to solve the problem, suggesting that teachers should improve their teaching methods. Therefore, this outlier did not have a significant impact on the analysis of the students' responses.

In fact, as shown in Figure 7, in terms of the grade evaluation of individual students out of 100 points, the average score for the quiz was 78.4 points, and average score for the assignment report was 69.5 points. These results are strongly correlated, suggesting that the proposed mathematics e-learning system can improve educational effectiveness. However, the number of participants in the study ($N = 37$) was insufficient. The number of students should be increased to more precisely verify the effectiveness of the method.

Finally, in (3), the students were particularly satisfied with learning new knowledge and skills in response to Q10 and, in general, did not feel stressed when operating the LMS. The free-form comments show that mathematics e-learning with a unified UI is well-received and accepted by students. Approximately 70% of students said that this learning environment was easier to understand than classroom learning. Only two out of the 39 students who enrolled withdrew from the course midway, and among the 37 students evaluated, three failed. The low withdrawal rate is considered to be because the students understood the mathematical content and achieved high satisfaction, as evidenced by approximately 87% of the students commenting that this teaching style, particularly the quizzes, was easy to engage with. However, some students' comments indicated that some quizzes had shorter time limits than others. A detailed analysis of the results in Table 3, discussed in Subsection 4.4.3, reveals that the time limits for the 13 quizzes require reconsideration. We plan to revise these quizzes in future courses and conduct a reevaluation.

However, it is difficult to conclude whether the educational effectiveness and high level of satisfaction shown by these results can be attributed to the unification of UI formula input or the support of teachers without further evaluation experiments. In this study, we were unable to directly evaluate MathTOUCH as a human-computer interaction, nor could we evaluate its usability. In future, we will conduct a usability test to evaluate these aspects and analyze the STACK answering process using a detailed feedback design.

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