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Development and Validation of an AR-PBL Local Wisdom-Based Colloid Chemistry Module

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Abstract: *Colloidal chemistry is often perceived as an abstract and difficult topic because many concepts involve microscopic phenomena that cannot be directly observed. This study aimed to develop and validate an Augmented Reality (AR)-based, Problem-Based Learning (PBL)-integrated, local-wisdom-oriented module for colloidal chemistry and to examine students' learning interest. This Research and Development (R&D) study used the 4D model (Define, Design, Develop, Disseminate), limited to the first three stages. The module was validated by three experts on teaching-material/media aspects (design, presentation, application, language, and graphics) and content aspects (accuracy and language). After revision, it was trialed with 36 undergraduate students in the Basic Chemistry course at the Department of Chemistry, Universitas Negeri Medan. Learning interest was measured using a 20-item questionnaire covering interest, attention, enjoyment, and engagement. Teaching-material/media validation yielded a mean of 3.85 (Very Valid), and content validation yielded 3.97 (Very Valid). The questionnaire showed excellent reliability (Cronbach's alpha = 0.985), with an overall mean learning-interest score of 3.69 on a 1–4 scale (very good). These findings indicate that the AR-based, PBL-integrated, local-wisdom-oriented module is valid, feasible, and associated with positive learning interest in colloidal chemistry. Further research is needed to examine its effects on cognitive learning outcomes using a more rigorous design.*

Keywords: *Augmented Reality; Problem-Based Learning; local wisdom; module validation; learning interest in colloidal chemistry*

INTRODUCTION

Education in the global era continues to develop alongside advances in science and technology, requiring learning systems to become more effective, relevant, and responsive to 21st-century demands. In this context, educators are expected not only to provide information but also to facilitate learning experiences that develop students' critical thinking, problem-solving abilities, and capacity to apply knowledge to real-life

situations (Kimianti & Prasetyo, 2019; Nabila et al., 2024). In science education, these competencies are particularly important because students need to understand scientific concepts, interpret natural phenomena, and apply scientific reasoning in everyday contexts (Bunawan et al., 2021; Kelp et al., 2023).

Despite these expectations, science learning in Indonesia continues to face challenges. The Programme for International Student Assessment (PISA) 2022 results indicate that Indonesian students' science performance remained below the OECD average (OECD, 2023). One contributing concern is the continued use of conventional instructional practices that emphasize information delivery and memorization rather than active engagement in critical thinking and problem solving (Fahrudin et al., 2021). These challenges are particularly relevant in chemistry because students are required to connect macroscopic observations, symbolic representations, and microscopic explanations. Colloidal chemistry is one example in which students need to understand microscopic phenomena such as the Tyndall effect, Brownian motion, and coagulation, which cannot be directly observed through conventional textbooks or static illustrations. Consequently, students may experience difficulties in constructing meaningful conceptual representations and connecting abstract concepts with observable phenomena (Bruce, 2022). This condition indicates the need for learning materials that provide both appropriate visualization and meaningful contextualization, particularly in Basic Chemistry at the university level.

Several approaches have been investigated to address these challenges from complementary perspectives. Problem-Based Learning (PBL) promotes active and student-centered learning by engaging students in authentic problems that require discussion, investigation, application of scientific concepts, and formulation of solutions (Al-tabani, 2014). Previous studies have reported that PBL can support higher-order thinking and problem-solving abilities while helping students connect theoretical knowledge with real-life problems (Hidayati et al., 2022; Ramlo et al., 2021; Susanto & Susanta, 2022). However, effective PBL implementation also requires learning resources that can help students interpret complex scientific phenomena.

Augmented Reality (AR) provides an opportunity to address the visualization aspect of this challenge. AR integrates virtual objects and information into the real-world environment, enabling learners to interact with representations of concepts that may otherwise be difficult to visualize (Agustin & Wardhani, 2023). In chemistry education, AR can represent molecular structures, chemical processes, and microscopic phenomena that are not readily observable through conventional instructional media. Previous studies have associated AR-based learning with conceptual understanding, learning interest, and active student involvement (Irma et al., 2024; Priyolistiyanto et al., 2024). Nevertheless, visualization alone does not necessarily provide a contextual learning experience; therefore, AR can be complemented by instructional approaches that connect scientific concepts with meaningful problems and students' environments.

Local wisdom offers such a contextual dimension. Local wisdom encompasses knowledge, values, practices, and cultural experiences developed within a particular community and can provide authentic contexts for connecting scientific concepts with students' everyday lives. Its integration into science learning can help students interpret scientific concepts through familiar cultural and environmental phenomena (Sanova et al., 2022; Muti'ah et al., 2023). In chemistry, local wisdom may be represented through natural resources, traditional production processes, and cultural practices related to chemical phenomena, including

traditional food-processing practices involving colloidal systems.

The integration of PBL, AR, and local wisdom therefore provides complementary functions within a single learning framework. PBL facilitates problem-oriented and collaborative learning, AR supports the visualization of abstract and microscopic phenomena, and local wisdom provides contextual connections between scientific concepts and students' surrounding environments. Previous studies have generally examined these approaches separately or in partial combinations. However, limited research has focused on the development and validation of an instructional module that systematically integrates AR, PBL, and local wisdom specifically for colloidal chemistry in Basic Chemistry at the university level. In addition, limited attention has been given to describing students' learning interest following a limited trial of such an integrated module.

To address this gap, the present study develops an AR-based instructional module integrated with PBL and oriented toward local wisdom for colloidal chemistry. The novelty of the study lies in the integration of interactive AR visualization, problem-based learning activities, and local-wisdom contexts within a single instructional module designed for undergraduate Basic Chemistry learning. The module is developed and validated through the Define, Design, and Develop stages of the 4D model and subsequently subjected to a limited student trial. Accordingly, this study aims to develop and validate the AR-based, PBL-integrated, local-wisdom-oriented module and to describe students' learning interest following its limited implementation. The findings are expected to provide evidence regarding the feasibility of an integrated technology-supported and contextual learning material for addressing abstract and microscopic concepts in colloidal chemistry.

LITERATURE REVIEW

Augmented Reality in Science and Chemistry Learning

Augmented Reality (AR) is a technology that integrates virtual objects, information, or digital representations with the real-world environment, allowing learners to interact with content in a more immersive manner (Abd Ghani, 2026). Its application in science and chemistry education is particularly relevant because many chemical concepts involve microscopic structures and processes that cannot be directly observed. Three-dimensional AR representations can provide visual support for concepts that are traditionally presented through static illustrations, potentially facilitating students' conceptual understanding and engagement (Agussalim, 2025; Apriani et al., 2021; Irma et al., 2024). In chemistry learning, AR has also been used to connect observable phenomena with particle-level representations, supporting students in relating different levels of chemical representation (Nst & Ariyanti, 2025; Ribič & Devetak, 2025). Thus, AR can function as a visualization medium for supporting the learning of abstract and microscopic chemistry concepts.

Problem-Based Learning in Chemistry Education

Problem-Based Learning (PBL) is a student-centered instructional model in which learning begins with contextual problems that require students to investigate, discuss, apply relevant knowledge, and formulate solutions. This approach provides opportunities for students to construct knowledge through active learning rather than relying primarily on information transmission (Al-tabani, 2014). Previous studies have reported that PBL can support higher-order thinking, problem-solving, and the application of theoretical knowledge to real-life situations (Hidayati et al., 2022; Ramlo et al., 2021; Susanto & Susanta, 2022). In chemistry education, the problem-oriented nature of

PBL is particularly relevant because chemical concepts can be connected to observable phenomena and everyday problems. However, when problems involve abstract or microscopic processes, students may require additional visualization and contextual support to investigate the problems effectively.

Integration of Augmented Reality and Problem-Based Learning

The integration of AR and PBL combines technological visualization with an active instructional approach. AR can provide representations of abstract scientific phenomena, while PBL can organize students' learning activities around contextual problems that require investigation and solution development. This combination allows visualization to function not merely as a presentation tool but as part of a problem-oriented learning process. Previous research has suggested that AR-supported PBL can facilitate students' understanding of difficult concepts while encouraging independent and collaborative problem solving (Kimianti & Prasetyo, 2019; Amriani et al., 2026). Therefore, integrating AR into PBL-based learning materials may provide a structured way to support both conceptual visualization and active learning.

Local Wisdom as a Context for Chemistry Learning

Local wisdom refers to knowledge, values, practices, and cultural experiences developed within a particular community. In education, local wisdom can provide authentic contexts through which students relate scientific concepts to phenomena that are familiar within their social and cultural environment (Alwasilah, 2020). Previous studies have indicated that learning materials incorporating local wisdom can support conceptual understanding and critical thinking by making learning more contextual and meaningful (Kimianti & Prasetyo, 2019; Sitanggang et al., 2026). In science and chemistry education, local wisdom can be represented through traditional food processing, natural resources, community practices, and other culturally relevant phenomena that can be explained using scientific concepts (Sanova et al., 2022; Muti'ah et al., 2023). Such contexts are particularly relevant to colloidal chemistry because several colloidal systems can be encountered in traditional foods and daily community practices.

Instructional Module Development and Validation

An instructional module is a structured learning resource designed to organize learning objectives, content, activities, and evaluation in a systematic sequence. For technology-supported learning, a module can integrate textual explanations, learning activities, visual representations, and interactive digital components within a coherent learning structure. The 4D development model proposed by Thiagarajan et al. (1974) provides a systematic framework consisting of Define, Design, Develop, and Disseminate stages. In development research, expert validation is conducted during the Develop stage to evaluate the quality and feasibility of the resulting instructional product before implementation with students. Validation may cover teaching-material and media aspects, including design, presentation, application, language, and graphics, as well as content-related aspects such as accuracy and language. The results of expert validation provide a basis for identifying weaknesses and revising the module before student trials.

Learning Interest in Chemistry Learning

Learning interest refers to students' positive tendency to attend to, enjoy, and actively participate in learning activities. In the context of instructional innovation, learning interest can be reflected through students' interest, attention, enjoyment, and engagement during learning activities (Risma Junita Amriani et al., 2026). These indicators are relevant when evaluating learning materials because a module that is visually

interactive, problem-oriented, and connected to students' contexts may influence how students attend to and participate in learning. AR provides interactive visualization, PBL provides opportunities for active problem solving, and local-wisdom contexts provide relevance to students' experiences. The combination of these characteristics therefore provides a theoretical basis for examining students' learning interest after using the developed module.

Synthesis of the Literature

The literature indicates that AR, PBL, and local wisdom address different but complementary dimensions of chemistry learning. AR supports the visualization of abstract and microscopic concepts; PBL provides a structure for active investigation and problem solving; and local wisdom connects scientific concepts with authentic cultural and environmental contexts. However, the existing literature identified in this study provides limited evidence on an instructional module that integrates all three components specifically for colloidal chemistry in undergraduate Basic Chemistry. This study therefore develops and validates an AR-based module integrated with PBL and oriented toward local wisdom, followed by an examination of students' learning interest after a limited trial. The literature provides the theoretical basis for the module's design, validation criteria, and assessment of students' learning interest.

METHODS

Research Design

This study used a Research and Development (R&D) design based on the 4D model (Define, Design, Develop, and Disseminate), limited to the Define, Design, and Develop stages, since the focus is on developing and validating the instructional module and examining students' learning interest toward it.

The Define stage identified curriculum requirements, student characteristics, and colloidal-chemistry content needing improvement. The Design stage produced the initial module draft. The Develop stage consisted of expert validation, revision, and a limited trial with students to assess learning interest.

Research Site and Time

This research was conducted at the Chemistry Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, Jalan Willem Iskandar, Pasar V Medan Estate, Medan, North Sumatra, from April to September 2026.

Population and Sample

The population consisted of students enrolled in the Basic Chemistry course at the Chemistry Department, Universitas Negeri Medan. The trial sample consisted of 36 students from one intact class, selected using a convenience sampling technique, as the class was predetermined by the course schedule rather than through random assignment of individual students (Sekaran, 2003).

Research Focus

This study focuses on: (1) the development and expert validation of an AR-based, PBL-integrated, local-wisdom-oriented instructional module for colloidal chemistry; and (2) student learning interest toward the module following a limited trial.

Research Procedure

1. Conducting the Define stage: analyzing curriculum requirements, student

characteristics, and colloidal-chemistry content in need of improvement.
2. Conducting the Design stage: drafting the AR-based, PBL-integrated, local-wisdom-oriented module, with AR content delivered via the Assemblr EDU application accessed through students' smartphones.
3. Conducting the Develop stage: (a) expert validation by three validators covering teaching-material/media and content aspects; (b) module revision based on validator feedback; and (c) a limited trial with 36 students across three sessions (2 lesson periods/session) to assess learning interest via questionnaire.

Research Instruments

1. Teaching-material/media expert validation sheet, covering five aspects (material design, presentation, application, language, and graphics), rated on a 1–4 Likert scale.
2. Content expert validation sheet, covering two aspects (content accuracy and language quality), rated on a 1–4 Likert scale.
3. Learning-interest questionnaire covering four aspects (interest, attention, enjoyment, and engagement), consisting of 20 items rated on a 4-point Likert scale. The questionnaire demonstrated very high internal consistency, with a Cronbach's alpha of 0.985 (n = 36; k = 20). All 20 items were considered valid, with corrected item-total correlations ranging from 0.804 to 0.911, exceeding the critical r value of 0.329 (df = 34, $\alpha = 0.05$). The alpha-if-item-deleted values ranged from 0.984 to 0.985, indicating that removing any individual item would not improve the overall reliability of the questionnaire.

Data Analysis Techniques

1. Validation Score Analysis.
Expert-validation scores from the teaching-material/media and content validation sheets were averaged per aspect and converted into an overall mean, interpreted using the following validity criteria:

Table 1. Category of Validation Score

Score Range	Category
3.25 – 4.00	Very Valid
2.50 – 3.24	Valid
1.75 – 2.49	Fairly Valid
1.00 – 1.74	Invalid

Learning-Interest Analysis.
Questionnaire responses were scored (SA = 4, A = 3, D = 2, SD = 1) and converted into a mean score per aspect and overall. Reliability was analyzed using Cronbach's alpha, and the mean scores were interpreted using the following criteria:

Table 2. Category Questionnaire responses

Mean Score (x)	Category
$x > 3.4$	Very good
$2.8 < x \leq 3.4$	Good
$2.2 < x \leq 2.8$	Fair
$1.6 < x \leq 2.2$	Poor

RESULT AND DISCUSSION

Module Development and Validation Results

The AR-based, PBL-integrated, local-wisdom-oriented module consists of nine components: (1) cover; (2) usage instructions, including procedures for accessing AR content through the Assemblr EDU application on a smartphone; (3) module identity, including learning outcomes and author information; (4) PBL-based learning activities, from local-wisdom-based problem orientation to evaluation and reflection; (5) colloidal-chemistry content covering dispersion systems, solutions, colloids, suspensions, colloid types and properties, and preparation, with three of five subtopics supported by AR markers; (6) assessment

items; (7) enrichment and remedial activities; (8) bibliography; and (9) Student Worksheets (LKPD) for each learning session. Colloidal chemistry was selected because it is closely related to real-world applications, including water treatment (Karnena & Saritha, 2022) and active-matter research (Nsamela et al., 2023). Validation was conducted by three lecturers from the Chemistry Education and Chemistry Department programs at Universitas Negeri Medan to obtain expert judgments and recommendations before the student trial. Two domains were assessed: teaching-material/media, covering design, presentation, application, language, and graphics; and content, covering content quality and language. The teaching-material/media validation results are presented in Table 3.

Table 3. Recapitulation of Teaching-Material/Media Expert Validation Results

Aspect	V1	V2	V3	Mean	Category
Material Design	3.75	3.75	4.00	3.83	Very Valid
Presentation	4.00	4.00	4.00	4.00	Very Valid
Application	3.50	3.50	4.00	3.67	Very Valid
Language	3.75	3.75	4.00	3.83	Very Valid
Graphics	3.88	3.88	4.00	3.92	Very Valid
Overall Mean	**3.78**	**3.78**	**4.00**	**3.85**	**Very Valid**

As presented in Table 3, the teaching-material/media validation yielded an overall mean score of 3.85, categorized as Very Valid. The presentation aspect obtained the highest mean score (4.00), indicating that the organization and delivery of the learning materials were considered highly appropriate by the validators. The application aspect obtained the lowest mean score (3.67), although it remained within the Very Valid category. The validators also provided qualitative recommendations, particularly regarding the need for additional illustrations for several colloidal-properties subtopics, more real-life examples of colloidal products, alignment of learning outcomes with the higher-education KKNI/OBE framework, and an increase in the cognitive level of the learning objectives from C1-C2 toward C3-C4.

The module was subsequently revised based on these recommendations. The revisions included: (1) adding illustrations to the colloidal-properties subtopic; (2) incorporating additional contextual examples of colloidal products from everyday life; (3) realigning the learning outcomes with the applicable higher-education curriculum framework; and (4) restructuring the PBL orientation and exploration stages to provide greater opportunities for students to independently investigate and discuss the presented problems.

Following the teaching-material/media assessment, content experts evaluated the scientific content and language of the module. The results of the content validation are presented in Table 4.

Table 4. Recapitulation of content expert validation results

Aspect	V1	V2	V3	Mean	Category
Content	3.90	3.90	4.00	3.93	Very Valid
Language	4.00	4.00	4.00	4.00	Very Valid
Overall Mean	**3.95**	**3.95**	**4.00**	**3.97**	**Very Valid**

As shown in Table 4, the content validation produced a mean score of 3.93 for the content aspect and 4.00 for language, resulting in an overall mean of 3.97, categorized as Very Valid. These results indicate that the module content was considered appropriate in terms of scientific accuracy, alignment with the learning outcomes of the Basic Chemistry course, relevance of the integrated North Sumatran

local wisdom, and clarity of scientific language. Taken together, the teaching-material/media and content validation results indicate that the module met the established validity criteria and was suitable for subsequent student trials after incorporating the validators' recommendations.

The validity results are also related to the theoretical principles underlying the module design. From a cognitive-load perspective, the integration of visual and verbal representations through AR was intended to support students in processing microscopic colloidal phenomena while minimizing unnecessary cognitive demands (Sweller, 1988). The PBL structure, meanwhile, was designed from a social-constructivist perspective, positioning students as active participants in knowledge construction through problem-solving, discussion, and interaction with peers (Vygotsky, 1978). The positive validation results, particularly for presentation (4.00) and graphics (3.92), provide empirical support for the appropriateness of these design features, although the validation scores themselves should be interpreted as expert judgments rather than direct measures of learning effectiveness.

The use of interactive three-dimensional AR was intended to facilitate students' mental representation of microscopic colloidal phenomena. This design rationale is consistent with recent research indicating that AR can support students' understanding of submicroscopic chemistry concepts by allowing interaction with virtual objects representing chemical phenomena (Nst & Ariyanti, 2025; Ribič & Devetak, 2025). Similar applications have been reported in AR-based e-modules for abstract chemistry topics (Fadhilah & Nasution, 2025) and contextual colloid-chemistry teaching materials for vocational students (Sianturi et al., 2025). These studies provide a relevant basis for incorporating AR into learning materials addressing abstract and microscopic chemistry concepts.

The PBL component was similarly designed to encourage students to engage in problem identification, investigation, discussion, and reflection. This design is consistent with systematic evidence indicating that PBL incorporating critical-thinking activities can support higher-order learning in higher education (Yu & Zin, 2023). In chemistry education, PBL-based learning has also been implemented alongside digital assessment to support the development and assessment of students' creative thinking (Nasrullah & Sari, 2025). Similarly, STEM-based PBL supported by interactive digital media has been reported to be associated with improved student learning outcomes (Azizah & Purba, 2025). Orhan (2024) further examined PBL implementation in higher education and reported differences in learning outcomes across instructional conditions. In the present module, authentic problems related to North Sumatran products, including coconut milk, tofu, and dodol, were incorporated to connect colloidal-chemistry concepts with students' everyday experiences (Al-Tabani, 2014; Sanova et al., 2022). This contextualization is consistent with ethnopedagogical approaches that integrate local knowledge into science learning and have been associated with increased learning interest and critical-thinking development (Silaban et al., 2025). Thus, the validation results and supporting literature collectively indicate that the module's AR, PBL, and local-wisdom components were grounded in established learning-design principles and

were considered appropriate by the expert validators before implementation with students.

Learning Interest

Students' learning interest after implementation of the AR-PBL module was assessed using a 20-item questionnaire covering four aspects: interest in learning, attention in learning, feeling of enjoyment, and engagement in learning. The questionnaire demonstrated very high internal consistency, with a Cronbach's alpha of 0.985 (n = 36; k = 20). All 20 items were considered valid, with corrected item-total correlations ranging from 0.804 to 0.911, exceeding the critical r value of 0.329 (df = 34, α = 0.05). The alpha-if-item-deleted values ranged from 0.984 to 0.985, indicating that removal of any individual item would not improve the overall reliability of the questionnaire. The results of the learning-interest questionnaire are presented in Table 5.

Table 5. Student learning-interest questionnaire results

No	Aspect	Indicator	Mean Score	Category
1	Interest in Learning	Curiosity and enthusiasm during AR-based instruction	3.68	Very Good
2	Attention in Learning	Focus and concentration during instruction	3.69	Very Good
3	Feeling of Enjoyment	Expressed satisfaction and comfort using the module	3.75	Very Good
4	Engagement in Learning	Active participation, discussion, and completion of PBL tasks	3.65	Very Good
Overall Mean			**3.69**	**Very Good**

As shown in Table 5, the overall mean learning-interest score was 3.69 on a 1–4 scale, categorized as Very Good. Among the four aspects, feeling of enjoyment obtained the highest mean score (3.75), followed by attention in learning (3.69), interest in learning (3.68), and engagement in learning (3.65). The high enjoyment score indicates that students responded positively to the learning experience provided by the module. The integration of augmented reality enabled students to interact with three-dimensional representations through their smartphones, which may have contributed to their positive learning experience. This finding is consistent with recent meta-analytic evidence reporting positive effects of AR-based learning environments on student motivation (Tzirides et al., 2024).

The attention (3.69) and interest (3.68) aspects were also categorized as Very Good, indicating that students generally maintained focus and demonstrated curiosity during the learning activities. The integration of North Sumatran local wisdom may have further enhanced the relevance of the learning content by connecting colloidal-chemistry concepts with familiar products and cultural practices. Previous studies have reported that integrating local wisdom into PBL-based learning materials can support scientific literacy and problem-solving by contextualizing abstract scientific concepts within culturally meaningful situations (Annam et al., 2024; Mubarak et al., 2026; Zainuri et al., 2025). This approach is also consistent with ethnoscience-oriented learning, which connects scientific concepts with students' local cultural knowledge (Utami et al., 2026).

The engagement aspect obtained the lowest mean score (3.65), although it remained within the Very Good category. This result may reflect the demands of PBL activities, which require students to participate actively, discuss problems, and construct knowledge more independently. For students who are more accustomed to conventional lecturer-centered instruction,

such learning activities may require an adaptation period before becoming fully habitual. Similar findings have highlighted the importance of repeated implementation and student familiarity when introducing active learning approaches (Amriani et al., 2026). Overall, the questionnaire results indicate that the AR-PBL module was associated with a Very Good level of student learning interest, particularly in terms of enjoyment, attention, interest, and active engagement. These findings suggest that the combination of augmented reality, PBL, and local wisdom provided a learning environment that students perceived as engaging and relevant to chemistry learning (Setiaji et al., 2025).

CONCLUSION

This study developed an AR-based, PBL-integrated, local-wisdom-oriented module for colloidal chemistry using the Define, Design, and Develop stages of the 4D model, validated the module, and described students' learning interest following its implementation. Expert validation rated the module as Very Valid, with overall mean scores of 3.85 for the teaching-material and media aspects and 3.97 for the content aspects, indicating that the module was suitable for student trials. In the limited trial, students demonstrated a very good level of learning interest, with a mean score of 3.69 on a 1–4 scale. The learning-interest questionnaire showed very high internal consistency (Cronbach's alpha = 0.985; n = 36; k = 20), while the engagement aspect obtained the lowest mean score among the four aspects, suggesting an area for further improvement. These findings indicate that the developed module was valid and was associated with a very good level of students' learning interest during the implementation. However, the study was limited to a single class (n = 36) at one institution, measured learning interest only after a short implementation period, and did not assess cognitive learning outcomes. The study therefore provides an initial approach to integrating AR-based visualization, problem-based learning, and local-wisdom contexts into chemistry instruction, particularly for abstract and microscopic topics. Future research should examine learning outcomes using a control-group or other comparative design and investigate the longer-term retention of both learning outcomes and learning interest.

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