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Development of Computer Hardware Learning Media Using Augmented Reality: A Study on Student Engagement and Understanding

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Abstract: This study aims to develop Augmented Reality-based learning media on computer hardware materials and investigate its impact on student understanding and engagement. The research employs the Research and Development (R&D) method with the ADDIE model. The study involved two lecturers as media experts, one informatics teacher as a material expert, and students in grades VIII-3 (control class) and VIII-4 (experimental class). Data collection techniques included interviews and questionnaires. Data analysis was conducted descriptively to assess expert validation and student involvement, as well as quantitatively through normality, homogeneity, t-test, and N-Gain calculation. The validation results showed that the media was highly feasible, with average scores of 97.5 from media experts and 62 from material experts. The N-Gain test revealed a greater increase in understanding in the experimental class (0.71) compared to the control class (0.41). Additionally, the average engagement score of students in the experimental class increased from 3.31 to 4.35, categorized as high, while the control class increased from 3.33 to 4.03, also categorized as high. The findings indicate that Augmented Reality-based learning media is feasible and effective in enhancing students' understanding and engagement with computer hardware materials.

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Introduction

The development of digital technology in the current era is taking place very rapidly and has a significant influence on almost all aspects of human life, including in the field of education. One form of technology that has now become an integral part of daily life is smartphones. No longer only used for communication, smartphones have become the main means of accessing various digital information and services quickly, easily, and flexibly (Andersson, 2022; Jha et al., 2022). Based on the latest global data, Indonesia occupies the fourth position as the country with the largest number of smartphone users, reaching 187.7 million people (Priori Data, 2024; GrabOn, 2025). This shows that this device has great potential to be used in adaptive and modern learning activities.

The use of smartphones in education provides opportunities to create flexible and independent learning. Nikou (2024) and Handoyo et al. (2023) stated that the use of this device allows students to access subject matter anytime and anywhere, adapting to their respective needs and learning styles. Jeong (2022) even emphasized that mobile technology such as smartphones is able to provide a more contextual learning experience and is integrated with the digital lives of today's students.

One of the visual technologies that can be integrated with smartphones and has high potential in learning is Augmented Reality (AR). This technology allows users to see two- or three-dimensional objects interactively in real-time and real-time environments, thus helping students visualize abstract concepts into more concrete (Nikou, 2024; Alzahrani, 2020). Sırakaya and Alsancak Sırakaya (2022) show that AR can deliver more engaging and meaningful learning content for students, while Marrahí Gómez and Belda Medina (2024) emphasize the potential of AR in creating more immersive learning experiences. In addition, Li (2023) states that this technology is able to simplify technical concepts through hands-on visualization that is easy to understand. In fact, Vidak et al. (2020) noted an increase in learning motivation of 31% in students who used mobile-based AR.

Research by Çakır and Cakiroğlu (2023) and Siki and Leba (2024) revealed that AR significantly improves student engagement and learning outcomes. Putra, Madlazim, and Hariyono (2024) also showed that the use of AR media is able to encourage students' active participation and strengthen understanding of the material presented. However, in Indonesia, the use of AR in education is still relatively limited. Many schools still rely on conventional methods such as one-way lectures or presentations (Setiawan et al., 2023; Aji & Taufiq, 2022), which is considered less effective in delivering technical and complex material. The low use of visual media makes it difficult for students to understand the content of the lessons, as well as has an impact on the lack of active participation in the class (Dewi et al., 2021; Siki & Leba, 2024). On the other hand, the main challenges that hinder the implementation of AR in schools include limited infrastructure, lack of teacher training, and low digital literacy (Sakr & Abdullah, 2024; Marrahí Gómez & Belda Medina, 2024).

One of the subject matter that is technical and still difficult for students to understand is computer hardware. This material is often delivered through verbal explanations or static images that do not help students in understanding the physical form and function of each component. Arici et al. (2021) state that conventional approaches are not effective enough to explain the relationships between parts of computer hardware. For this reason, Setiawan et al. (2024) introduced the use of markerless AR technology as a medium for visualizing computer hardware, which has been proven to significantly improve students' understanding. However, most of the AR learning media developed to date is still desktop-based. Partiwi (2019), for example, developed AR media with a file extension (.exe) that can only be run through a laptop or computer device. This is an obstacle because not all students have access to these devices at home. Instead, most students already own and are familiar with using smartphones. In this regard, Nikou and Economides (2022) and Lampropoulos et al. (2022) mentioned that smartphone-based learning media offer greater flexibility, wider accessibility, and better affordability, especially in educational environments that still face technological constraints. Previous research using Augmented Reality (AR) in computer hardware learning is still mostly desktop-based, so access is limited only through computers or laptops and does not reach the needs of students who use more smartphones. In addition, the focus of previous research was more focused on improving cognitive understanding, without in-depth measuring student involvement in learning. This research is different because it develops smartphone-based AR media that is more flexible, practical, and in accordance with the devices that students commonly have. This innovation is not only oriented towards improving the understanding of computer hardware materials, but also measures student engagement comprehensively through behavioral, emotional, and cognitive aspects using the School Engagement Measure (SEM) instrument.

Based on this explanation, the scientific novelty of this research lies in the development of Augmented Reality-based learning media that can be accessed through smartphones, especially to support learning on computer hardware materials at the junior high school level. This innovation combines an interactive visual approach with digital devices that the majority of students already have, so that it can improve visual understanding

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of concepts while encouraging active involvement in the learning process. This media is designed to simplify technical concepts, present more engaging learning, and expand access to learning technology more evenly. Thus, this innovation is expected to make a significant contribution to the world of education.

The use of AR in informatics learning is expected to answer the challenge of low student interest and understanding of technical materials. Interesting learning media will help students become more active and enthusiastic in participating in learning activities. In addition, this approach supports strengthening students' competence in understanding rapidly evolving technology. The use of AR is also in line with digital trends that are increasingly familiar with students' lives. This study aims to develop Augmented Reality-based learning media on computer hardware materials and determine its influence on student understanding and engagement. This media is expected to help students understand computer hardware concepts in a more in-depth and interactive way. In addition, the use of this media also aims to increase students' active involvement in the learning process. This research is expected to contribute to the development of learning innovations in the increasingly advanced digital era.

Research Method

This research used the Research and Development (R&D) method that adapts the ADDIE model, namely Analysis, Design, Development, Implementation, and Evaluation (Sugiyono, 2017). This model was chosen because it could facilitate the process of developing *Augmented Reality* (AR)-based learning media in a systematic and structured manner, as well as testing the effectiveness of its use on student understanding and engagement. The research design used was quasi-experimental with the Pretest-Posttest Nonequivalent Control Group Design model. This design involved two different classes that were not randomly selected, namely one experimental class that used AR-based media and one control class that used conventional learning methods. Both classes were given a pretest before treatment and a posttest after treatment to measure improved learning outcomes. The research population was all grade VIII students of SMP Negeri 8 Tarakan for the 2024/2025 school year, which totals 180 students. The sampling technique was carried out purposively by considering input from the subject teacher. The selected sample was class VIII-4 as the experimental class and VIII-3 as the control class, each consisting of 30 students.

The research instrument consists of several types, including: (1) a questionnaire of needs given to students and teachers of informatics at the initial stage to explore information related to the needs of learning media; (2) a validation questionnaire used by media experts and subject matter experts to assess the feasibility of the developed media; (3) pretest and posttest questions to measure students' understanding of computer hardware materials; and (4) student engagement questionnaires compiled based on the School Engagement Measure model (Fredricks et al., 2004), which includes three main dimensions: behavioral, emotional, and cognitive. Media development was done using Assemblr EDU software for AR content creation and CorelDRAW X7 for designing visual materials. Media is accessed using Android smartphone devices with minimum specifications of 4 GB of RAM and an active internet connection. The presence of researchers was active and directly involved in the process of implementing media in the experimental class, starting from media introduction, learning process assistance, to data collection. The presence of the researcher was active and directly involved in the media implementation process in the experimental class. The researcher accompanied the students for six meetings (each lasting 2 × 40 minutes) according to the Informatics subject schedule. At the first meeting, the researcher introduced AR media

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and provided a pretest of understanding and initial involvement questionnaire. The second to fifth meetings were focused on assisting the use of AR media in learning computer hardware components. At the sixth meeting, the researcher collected final data in the form of a posttest of understanding and a student engagement questionnaire. Thus, data collection was carried out in a structured manner through several stages, namely expert validation (1 time), pretest-posttest understanding (2 times), and student involvement questionnaire (2 times).

The data obtained was analyzed using several techniques. The data obtained from expert validation was processed descriptively to determine the level of media eligibility, while the improvement of student understanding was analyzed using a comparison of pretest and posttest scores with the N-Gain formula. In addition, normality and homogeneity tests were carried out as a prerequisite for the t-test. Independent t-tests were used to find out the significant differences between experimental and control classes, both in terms of student understanding and engagement. This research was carried out for approximately three months in the even semester of the 2024/2025 school year and was located at SMP Negeri 8 Tarakan. The validation of the research results was carried out by triangulating sources, namely through a combination of data from students, teachers, and expert validators, to ensure the accuracy and reliability of the data obtained.

Results and Discussion

This research was motivated by students' low understanding of computer hardware materials and the lack of student involvement during learning. Based on the results of needs analysis through questionnaires and interviews with informatics teachers, it was found that 83% of students stated that they had difficulty understanding hardware material because previous learning media had not been able to describe computer components visually and contextually. This has a direct impact on the low student engagement as seen from the lack of enthusiasm, interaction, and participation in the learning process.

As a solution to this problem, the researcher developed *an Augmented Reality* (AR)-based learning media using the Assemblr EDU application. This media features three-dimensional visualizations of various computer hardware components such as CPUs, RAM, motherboards, and more, which can be played, zoomed in, and learned directly by students through a smartphone device. The display of Augmented Reality-based learning media can be seen in Figure 2 below.

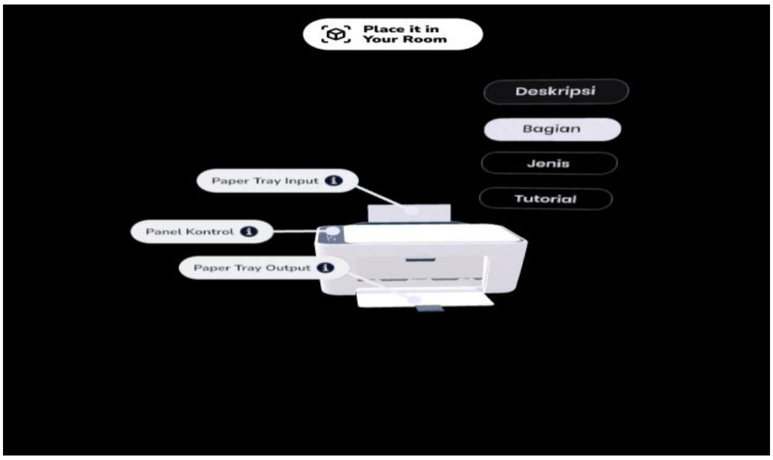

Figure 2. Display of Augmented Reality learning media

The media developed was first validated by two media experts and one material expert. The validation results showed that the media met the eligibility requirements with the category of "very feasible" in the media aspect and "very feasible" in the material aspect. The results of

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this validation show that AR media has met the feasibility criteria in terms of design, navigation, clarity of material, and ease of use, so that it is feasible to implement in Informatics learning.

Table 1. Validation Results of Media Experts and Subject Matter Experts

Assessment Aspect	Average Score	Category
Material Expert	97,5	Very feasible
Media Expert	62	Very feasible

Based on the results of validation from material experts, AR learning media is stated to be very feasible to use with minor revisions, especially in the aspects of material improvement and completeness of supporting information. Media expert validators also stated the media was very decent, with some minor suggestions regarding color suitability, text readability, and navigation clarity. The validation results show that the developed learning media is ready to be used in learning and is suitable for classroom testing.

Improved Student Understanding

The application of Augmented Reality-based learning media in computer hardware materials at SMP Negeri 8 Tarakan has been proven to have a significant impact on improving student understanding. The improvement of students' understanding of computer hardware materials in this study was analyzed based on *the results of the pretest* and *posttest* given to two groups, namely the control class and the experimental class. The two groups received the same material, but were differentiated based on the way it was delivered: the control class followed learning using conventional media, while the experimental class used *Augmented* Reality-based learning media. Comparison of results before and after learning provides a clear picture of how much impact learning media has on student understanding.

The effectiveness of AR media in improving students' understanding is reflected in the results of the pretest and posttest conducted on two groups, namely the experimental class (using AR media) and the control class (using conventional methods).

Table 2. Average Results of *Pretest* and *Posttest* Student Comprehension

Kelas	*Pretest*	*Posttest*
Control	57,50	75,83
Experiment	48,17	84,83

The effectiveness of AR media on improving student understanding is reflected in the results of pretest and posttest measurements conducted in two groups, namely the experimental class using AR media and the control class that follows conventional learning. The results of the pretest showed that the average score of students in the experimental class was 48.17, while in the control class it was 57.50. After the learning process, the posttest score of the experimental class increased to 84.83, while the control class increased to 75.83. The difference in score improvement in the experimental class was 36.66 points, almost double compared to the control class which only increased by 18.33 points. The difference in improvement between these two classes indicates that the learning media used in the experimental class is able to have a greater impact on student understanding than the learning method in the control class.

Table 3. Normality Test Results

Group	Test Stages	L_{count}	L_{tabel}
Control	*Pretest*	0,093565	0,16176
	Postest	0,14355	0,16176
Experiment	*Pretest*	0,011452	0,16176
	Postest	0,09204	0,16176

Table 4. Homogeneity Test Results

Test	F_{count}	F_{tabel}	Conclusion

Before	1,297	1,86	Homogen
After	1,86	1,86	Homogen

The normality test in this study used the Liliefors test with a significance level of 0.05. The results of the analysis showed that the total Lcal values in the pretest and posttest data, both for the control and experimental classes, were smaller than the Ltab, so it can be concluded that the data is normally distributed. Furthermore, a homogeneity test was carried out using the classical F test to determine the similarity of variance between groups. Based on the calculation results, it was obtained that the Fcal value in the pretest was 1.29727 and in the posttest was 1.85467, both of which were smaller than the Ftable of 1.86. Therefore, the data is stated to have homogeneous variance. Thus, it can be concluded that the data has met the assumptions of normality and homogeneity, making it worthy of further analysis using a parametric statistical test, i.e. the t-test.

Table 5. Results of the Student Comprehension t Test

Test	t_{count}	t_{tabel}	Result
Before	2,49	2,001	Signifikan
After	3,492	2,001	Signifikan

The results of the t-test showed that before treatment, the tcal value was 2.49, and after treatment increased to 3.49. These two values are greater than the table of 2.001, which means that there is a significant difference between the experimental and control classes, especially after the application of the treatment. This proves that the learning media used in the experimental classroom makes a real contribution to improving student understanding. To measure the magnitude of the increase, further analysis was carried out through the calculation of N-Gain, the results of which are presented in the next table.

Table 6. N-Gain Value Test Results

Class	Score (Before)	Score (After)	N-Gain	Category
Control	57,50	75,83	0,41	Medium
Experiment	48,17	84,83	0,71	High

Based on the N-Gain value listed in Table 4, it can be concluded that the learning media applied in the experimental classroom has proven to be effective in improving student learning outcomes. This can be seen from the N-Gain value of 0.71 which is in the high category in the experimental class, while the control class only gets a value of 0.41 which is relatively medium. This quite striking difference shows that the use of such media has a significant positive influence on student understanding. Therefore, this learning media deserves to be considered an effective tool in the learning process because it is able to significantly increase student understanding compared to classes that do not use these media.

This finding is strengthened by the results of Alawiyah's research (2024) which shows that the use of AR media in learning mathematics to build a space is able to significantly improve students' spatial understanding. In addition, research by Lampropoulos et al. (2023) states that AR media improves students' ability to build spatial and conceptual relationships, especially in abstract and technical materials. Research by Nengsih et al. (2023) on ecosystem learning also found that AR media contributes to improving student understanding through higher visualization and interactivity than print media or ordinary impressions.

Increased Student Engagement

Student involvement in learning is an important indicator that determines the quality of the learning process. student involvement in this study was conducted using *the School Engagement Measure* (SEM) instrument developed by Fredricks and colleagues. *The School Engagement Measure* (SEM) is a comprehensive and reliable measurement tool to assess the extent to which students are involved in learning activities (Ramadhani & Purwono, 2023). In

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this study, SEM plays an important role in being able to provide a comprehensive picture of students' learning experiences, which includes active actions, feelings towards open material, and critical thinking they do during the learning process. This instrument consists of three main dimensions, namely behavioral engagement, emotional engagement, and cognitive engagement. This Increased Engagement includes three main dimensions, namely behavioral (active participation in learning activities), emotional (pleasure, enthusiasm, and interest in lessons), and cognitive (effort and thinking strategies in understanding the material in depth). This engagement model refers to the theoretical framework of Fredricks, Blumenfeld, and Paris (2004), which states that full student involvement will improve attention, motivation, and learning outcomes.

Table 7. Student Engagement Pretest and Posttest Results

Class	Before	After
Control	3,33	4,03
Experiment	3,31	4,35

Based on the table above, it can be seen that the students' involvement before the treatment (pretest) in both classes was relatively balanced, with an average score of 3.31 in the experimental class and 3.33 in the control class. This shows that at first, the conditions of student involvement in both groups were almost the same. However, after learning, there was a significant increase in involvement in the experimental class, which was +1.04 points, from 3.31 to 4.35. In contrast, the increase in the control class was only +0.70 points, from 3.33 to 4.03. This difference in improvement shows that the use of *Augmented Reality* (AR) media has a greater impact on increasing student engagement than conventional learning methods.

Table 8. Normality Test Results

Group	Test Level	L_{count}	L_{tabel}
Control	*Pretest*	0,16079	0,16176
	Postest	0,12411	0,16176
Experiment	*Pretest*	0,12329	0,16176
	Postest	0,15579	0,16176

Table 9. Homogeneity Test Results

Test	F_{count}	F_{tabel}	Conclusion
Before	0,72108	1,86	Homogen
After	0,6152	1,861	Homogen

The normality test using the Liliefors formula shows that all data are distributed normally. In the control class, the pre-learning Lcal value was 0.16079 and after learning was 0.12411, both smaller than the Ltable of 0.16176. Similarly, in the experimental class, the value of Lcal before learning was 0.12329 and after learning was 0.15579, which is also smaller than the Ltable of 0.16176. Furthermore, the results of the homogeneity test showed that the data of the two classes had homogeneous variance, indicated by the Fcal value of 0.6152 which was smaller than the Ftable of 1.861. Because the data is normally distributed and homogeneous, a t-test is performed to see the difference in student engagement between the two classes.

Table 10. Student Engagement t-Test Results

Test	t_{hitung}	t_{tabel}	Result
Before	2,49	2,001	Signifikan
After	3,492	2,001	Signifikan

The results of the t-test showed that the tcal value of 2.856 was greater than the ttable of 2.001. Thus, there was a significant difference between student engagement in the control class and the experimental class after learning. This proves that the use of learning media applied to experimental classes is effective in significantly increasing student engagement.

However, while most students experience increased engagement as comprehension increases, there are cases that show a different trend. There was one student who experienced a decrease in engagement scores but his understanding increased significantly.

The decrease in score may be due to a decrease in motivation or other non-academic factors. Nevertheless, a sharp increase in comprehension scores shows that Augmented *Reality-based* media has a positive impact, particularly in helping students who initially have low abilities to better understand the material through visual and interactive approaches. This shows that the level of student involvement does not always move in line with the learning outcomes. Some students may not show an increase in involvement explicitly, but still gain a high level of understanding thanks to learning methods that suit their learning style (Nicholson et al., 2021). Therefore, it is important for teachers to not only rely on one indicator in assessing learning success, but also to consider the individual approach and specific conditions of each student (Yue, 2023).

Increased student engagement can be explained based on three dimensions of engagement. In the aspect of behavioral engagement, which is one of the dimensions of *the School Engagement Measure* (SEM), students in the experimental class showed a significant increase in terms of activeness in following lessons, adherence to class rules, and involvement in discussion and assignment completion. They appear to be more focused, enthusiastic about answering questions, and show better consistency of attendance during learning. This is in line with the findings (Patmisari et al., 2021) which states that student behavioral involvement is reflected in active participation such as working on problems, appearing in front of the class, expressing opinions, and responding to ideas from friends. Despite differences in participation skills between students, good classroom management has been proven to overcome these gaps (Asad et al., 2021). Thus, while SEM focuses on measuring engagement, an effective classroom management strategy remains an important factor in increasing student behavioral engagement.

Based on these results, it can be concluded that the use of Augmented Reality-based learning media has proven to be effective in increasing student engagement. This media not only increases engagement in terms of behavior, but also strengthens the emotional and cognitive aspects of students during the learning process. Therefore, Augmented Reality-based learning media is very feasible to be applied as an innovative solution to create a more interactive, interesting, and meaningful learning atmosphere.

In addition to increasing engagement in general, it is worth underlining that AR-based learning media has a significant influence on the emotional and cognitive dimensions of students. On the emotional side, students in experimental classes reported feeling more enthusiastic and motivated when learning computer hardware components. Some students stated that this medium made learning feel "like playing a game" and "more fun than just looking at pictures in a book". This shows that the use of AR is able to create an enjoyable learning experience, while increasing curiosity and emotional attachment to the material.

In the cognitive aspect, AR media helps students to more easily understand technical concepts through three-dimensional visualization. One student even revealed that he only really understood the motherboard's function after seeing a 3D display that could be rotated and zoomed in. This concrete quote reinforces that an interactive visual approach not only deepens understanding, but also encourages students to use more analytical thinking strategies in understanding the relationships between computer hardware components.

From a practical perspective, the results of this study have important implications for educators and policymakers. Teachers can utilize smartphone-based AR media to present learning that is more contextual, interesting, and in accordance with the characteristics of the

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digital generation. It also provides a solution to the limitations of conventional visual media in schools. For policymakers, these findings underscore the need for support in the form of providing digital infrastructure, teacher training, and the integration of immersive technologies such as AR into the curriculum. With this support, AR-based media has the potential to not only increase students' understanding and involvement in certain materials, but also strengthen the quality of learning in various fields of study.

Conclusion

Augmented Reality (AR)-based learning media on computer hardware materials has been successfully developed using the ADDIE model. The development process through the stages of analysis, design, development, implementation, and evaluation has produced interactive and easy-to-use media. The validation results showed that the media was in the very feasible category, with an average score of 97.5 from media experts and 82.43 from material experts. This showed that the developed meida met the feasibility aspects in terms of content, appearance, navigation and benefits in learning.

The use of Augmented Reality-based learning media has proven to be effective in increasing student understanding and engagement. The results of the N-Gain calculation showed that the increase in students' understanding of the experimental class reached 0.71 (high category), higher than the control class which only reached 0.41 (medium category). In terms of engagement, the average engagement score of the experimental class students increased from 3.31 to 4.35, while the control class only increased from 3.33 to 4.03. This shows that Augmented Reality-based learning media is able to facilitate students to understand the material better and encourage active involvement in the learning process.

Recommendation

Teachers are expected to be able to use Augmented Reality media in a planned, structured, and directed way in teaching activities. with the support of adequate devices and the design of learning activities that are in accordance with the characteristics of students. The use of Augmented Reality learning media not only enriches the learning experience through 3D visualization, but is also able to bridge abstract concepts into more concrete and easy to understand for junior high school students. Going forward, this media should not only display three-dimensional objects staticly, but also be developed with functional simulation features. For example, students can simulate how hardware components work such as the boot process, the flow of data from input to output, or interactions between devices in the form of interactive animations. With the simulation feature, students can not only see the shape of the device, but also understand how it works dynamically. This is considered important in helping students develop high-level thinking skills, including analysis and problem-solving.

This media also has great potential to be further developed in terms of content and features. The addition of elements such as interactive quizzes, audio narrations, and integration with Learning Management Systems (LMS) will increase the effectiveness and scalability of its use. Further research is suggested to explore this aspect and expand the application of media to other materials or levels of education, so that the benefits of AR technology in education can be felt more broadly, deeply, and sustainably.

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