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Breaking disciplinary silos in elementary education: a case study leveraging large language models

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Abstract

Our exploratory single-subject case study documents an artificial intelligence (AI)-integrated, fully digital homeschooling framework implemented during Grade 1 and early Grade 2 (ages 6–7). We demonstrate that leveraging large language models (LLMs) as an intellectual exoskeleton makes advanced, interdisciplinary projects feasible within an elementary curriculum, with AI acting as the crucial connective tissue for a highly personalized and adaptive curatorial process. Central to our approach is the "verifier" pedagogical model, which transitions the learner from passive consumer to active builder and critical auditor of machine-generated hallucinations and inaccuracies in text, logic, or code, directly counteracting cognitive debt. We feature several visually captivating student-driven projects including programmed animations to study music and wave physics, the design of a custom 3D virtual globe for geography, visualizing complex computer science algorithms, and the authorship of custom multilingual copy-tracing books for fine motor skills. We leverage specialized, ergonomically safe, and distraction-free technology to create a permanent cloud-based digital record of lectures, student progress, and course material. Our approach successfully dissolves the traditional silos between languages, arts, and sciences, suggesting that such an integrated environment allows for the immediate practical application of theoretical knowledge. This could equip young learners with the technological command, critical thinking, and verification skills required to navigate a future defined by exponential change. The relative simplicity of elementary educational projects provides a transparent, cross-disciplinary lens for foundational interaction patterns through which the mechanics of AI-augmented synthesis and cognitive scaffolding can be rigorously examined and adapted for more complex academic tiers.

Keywords: Artificial intelligence-integrated pedagogy, Artificial intelligence literacy, Large language models, Human-artificial intelligence interaction, Interdisciplinary curriculum, Constructionism

Statements and Declarations

Author Contributions

KP served as the Teacher and Principle Investigator for the study, developing the core AI-integrated pedagogical framework, establishing the “verifier” model, and designed the interdisciplinary curriculum flow based on an iterative feedback loop from VP and SB. VP served as the student and the primary subject of the case study, actively participating in all documented learning activities. SB served as the parent, teaching support, and the project/software/hardware administrator. Advanced software projects went through multiple iterations of AI and human development by KP, SB and VP in that order. VP played an active role in data creation and curation, generating the preliminary results/images for all the visual projects showcased, followed by advanced formatting for formal presentation by SB and KP. Resource curation from open source educational resources was performed by SB and KP, with feedback from VP. VP curated and drafted the preliminary list of all the use cases presented in this article based on classroom learning. KP and SB wrote the majority of the manuscript with contributions and feedback from VP. In addition to the role of AI as elaborated thoroughly in the article, it was also used for copy editing the final manuscript with substantive reviews, edits and verification by the authors.

Competing Interests

The authors declare no competing interests.

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1. Introduction

The rapid maturation of Generative Artificial Intelligence (GenAI) and Large Language Models (LLMs) has altered how information is synthesized and communicated across disciplines (Wang et al., 2025; Kumar 2024; Sapkota et al., 2026; Fei et al., 2024). While traditional elementary education has historically focused on the acquisition of foundational skills through rote memorization and subject-specific silos, the emergence of generative AI offers a unique opportunity to reimagine early childhood pedagogy. Recent research suggests that the integration of AI in early childhood education (ECE) can significantly influence cognitive development and social interactions, provided the tools are used to augment rather than replace human guidance (Suresh and Misra, 2024; Lee et al., 2024; Fikri and Rhalma, 2024). This exploratory single subject case study utilizes the foundational environment of a digital homeschooling framework for a student (age 6-7 years) during Grade 1 and the early months of Grade 2 (years 2024-25) as a laboratory exploring how AI can bridge the gap between simple elementary concepts and complex, cross-disciplinary applications. Rather than presenting a universally standardized curriculum, this study offers an architectural proof-of-concept. It examines how human-AI collaborative dynamics can be engineered as a pedagogical force multiplier to dissolve traditional disciplinary silos, enabling an early primary learner to design complex computational artifacts while cultivating critical AI literacy through systematic error auditing. The relative simplicity of our AI-integrated elementary education framework provides fundamental understanding that could potentially be adapted to complex academic tiers such as higher education, professional development, and lifelong learning contexts.

The past few years have marked a pivotal shift, moving Large Language Models (LLMs) from theoretical research to publicly accessible chat-based interfaces (Wang et al., 2025; Kumar 2024). Tools like Open AI's ChatGPT, xAI's Grok, or Google Gemini, which leverage massive datasets to recognize, summarize, translate, and generate content, have become ubiquitous, fundamentally changing how users interact with digital information. This public availability has made powerful cognitive assistance - an "intellectual exoskeleton" - instantly accessible to a global audience. These tools operate by predicting the most statistically probable sequence of words in response to a user's prompt, but while powerful, they are not infallible. Their tendency to generate plausible but incorrect information, known as hallucinations, is a key challenge that necessitates a corresponding shift in educational focus from information retrieval to critical verification (Anh-Hoang et al., 2025).

1.1 The Theoretical Foundation: Beyond Traditional Models

Our approach aligns with the idea of "Constructionism" which posits that learning is most effective when students are actively engaged in making tangible objects in the real world (Papert and Harel, 1991; Papert 2020). In a traditional setting, a 6-year-old's ability to "construct" is often limited by their fine motor skills or their lack of technical vocabulary. By using AI as an "intellectual exoskeleton," we remove these mechanical barriers, allowing the student to engage

in complex construction - such as programmatically generating music or 3D visualizations - while simultaneously mastering the underlying syntax, music structure, or mathematics.

Furthermore, this educational model extends the foundational idea of the Zone of Proximal Development (ZPD) (Vygotsky 1978), which defines the space between what a learner can achieve independently and what they can achieve with the guidance and collaboration of a more capable peer or instructor. Our proposed model leverages this principle as the teacher dynamically assesses the learner's current developmental level and utilizes advanced artificial intelligence as a dynamic scaffold to present the skills and knowledge that are just beyond their independent grasp. By continually recalibrating the learning material to operate within this optimized zone, the model ensures that the learning experience is both challenging enough to promote growth and supportive enough to prevent frustration, thus maximizing the efficiency and effectiveness of the student's cognitive development. For example, it allows the teacher to spontaneously elevate the curriculum or a topic of discussion from “6-year-old” to a "15-year-old” level of language and logic, challenging the student to reach beyond age-graded expectations while providing the necessary linguistic and technical support to ensure comprehension.

1.2 Breaking the Silos: The Interdisciplinary Necessity

Educational research has long criticized the "siloing" of subjects, where mathematics, language, and science are taught in isolation (Warkentien et al., 2022). For a young learner, this fragmentation can lead to a lack of perceived relevance. Current trends in interdisciplinary studies suggest that practical application is the strongest driver of retention (Chiang et al., 2022; Raja and Bhalla, 2021). However, implementing truly integrated lessons (e.g., teaching the physics of waves alongside the programming of music and the maths of decimals) is traditionally difficult because it requires the educator to possess deep expertise across multiple domains simultaneously, in addition to a significant time requirement to synthesize the content.

LLMs solve this "curatorial bottleneck." As demonstrated in our use cases, AI allows the teacher to integrate disparate fields at the "speed of thought," providing the interpretive tissue between, for example, the “Bisection Method” for computing roots in mathematics and “Binary Search” of a list in computer science. This allows for a "Curriculum of One" that is not bound by the limitations of standardized textbooks but is instead driven by the student’s own curiosity and progression. This curricular efficiency is a foundational design principle, ensuring the student has ample capacity for a holistic experience that includes extracurricular activities such as sports, fine arts, and meditation, which are often compromised by highly intensive academic schedules.

1.3 The Current Landscape of AI in Education

Most current implementations of AI in education focus on the "Intelligent Tutoring System" model (Lin et al., 2023). A review of recent literature indicates that while AI tools are becoming

ubiquitous as remedial assistants or Socratic guides, their pedagogical impact is deeply tied to the specific roles and interaction quality between the teacher, the student and the AI (Chen et al., 2020; Fikri & Rhalma, 2024). In early childhood and pediatric education, these systems are recognized for their potential to provide personalized scaffolding and facilitate complex interdisciplinary connections that would otherwise be inaccessible to young learners (Suresh and Misra, 2024; Cai et al., 2025; Cimino et al., 2025). However, recent findings caution against an over-reliance on generative assistants, suggesting that if AI is used to bypass the struggle of creation rather than to support it, students may accumulate 'cognitive debt' - a state where the ease of AI-assisted output prevents the development of deep, structural understanding (Kosmyna et al., 2025; Bastani et al., 2025).

Our model incorporates AI-supported education by pivoting the student's role toward a "Verifier" model of literacy. In an environment where generative models frequently produce plausible but factually untethered 'hallucinations,' we posit that a primary skill for the modern learner is not information retrieval, but rigorous critical verification (Anh-Hoang et al., 2025). By systematically involving the student in the auditing of AI-generated study materials, quizzes, and code, we foster a level of "AI Literacy" and skepticism that is needed for effective deployment of educational technology in early childhood settings (Suresh & Misra, 2024; Cimino et al., 2025). Such proactive engagement serves as a critical safeguard against the accumulation of 'cognitive debt,' ensuring that the student masters the underlying logic and structural nuances of a subject rather than outsourcing the cognitive labor to the machine (Kosmyna et al., 2025; Bastani et al., 2025).

1.4 The Role of the Fully Digital Environment

Finally, this case study explores the infrastructure of a fully digital classroom. Unlike traditional "EdTech" which often adds screen-time as a supplement to paper, our environment utilizes e-ink technology and cloud-integrated workflows to replace physical paper entirely, while keeping ergonomic safety a key priority. This ensures that every lesson, note, and interdisciplinary project is part of a permanent, searchable record. This digitization allows for individual reproducibility - enabling the student to see how their ideas have evolved from Grade 1 onwards, while preparing them for a professional world that is increasingly paperless and data-driven.

1.5 A Practitioner-Researcher Model

A fundamental distinction of this work lies in the unique, dual qualifications of its authors. While most academic discourse on AI in early childhood and elementary education is conducted either by theorists or by AI researchers without direct, daily, student-facing experience, this paper actively bridges that divide. The authors are active scientific researchers in fields such as neuroscience, artificial intelligence, data science, and applied dynamical systems, who are simultaneously the curriculum designers and primary educators for the student in this case study. This unique 'practitioner-researcher' perspective ensures the framework presented is

grounded not only in sound pedagogical principles but also in a sophisticated, current, and hands-on understanding of the frontier technology it employs.

2. Methods and Homeschool Infrastructure

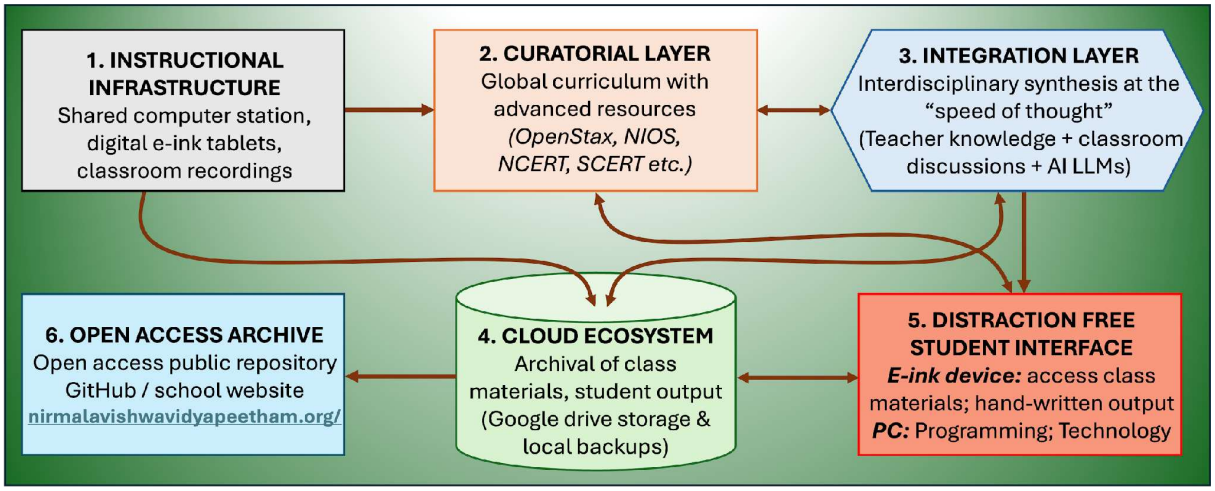


***Figure 1. Integrated AI-Augmented Pedagogical Workflow**: This diagram illustrates the flow from open-source resource curation and AI-supported synthesis to the interdisciplinary learning environment, culminating in permanent, open-access digital documentation in a cloud based ecosystem.*

2.1 Curatorial Strategy and Open Resources

A central pillar of our methodology is the use of high-quality, publicly available educational resources to construct a rigorous yet adaptable curriculum, which encompasses a broad range of subjects, including linguistic studies (English, Telugu, Hindi), Mathematics, Programming and Algorithms, Technology, Science, Social Studies, and Music, in addition to supplementary activities such as Sahajayoga meditation (https://sahajayoga.org.in/), sports and fine arts. Instead of relying on a single publisher, we curate materials from a global library of open-source texts.

- **Basic Curriculum and Science Textbooks:** We utilize curriculum materials from Georgia Department of Education (https://gadoe.org/), Indian National Council of Educational Research and Training (NCERT - https://ncert.nic.in/), National Institute of Open Schooling (NIOS - https://nios.ac.in), Telangana State Council of Educational Research and Training (https://scert.telangana.gov.in/e-Textbooks.htm) , and Andhra Pradesh State Council of Educational Research and Training (https://apscert.gov.in/).
- **Advanced resources:** The basic curriculum is supplemented by advanced texts on science, language, literature, and fine arts from OpenStax (https://openstax.org/) (Stafford and Flatley, 2018), the Open Textbook Library (https://open.umn.edu/opentextbooks/), Open Textbook Publishing

(https://openbooks.lib.msu.edu/), the Internet Archive (https://archive.org/), Project Gutenberg (https://www.gutenberg.org/), Tirumala ebooks (https://ebooks.tirumala.org/) and the National Digital Library of India (https://ndl.iitkgp.ac.in/ndl_se).

AI serves to build the crucial connective tissue within this highly personalized and adaptive curatorial process. Our curriculum transcends beyond mere content aggregation to actively integrate and synthesize disparate educational resources into a coherent, interdisciplinary learning experience. For instance, the system doesn't just present isolated lessons in physics, decimal mathematics, and music theory. Instead, it intelligently weaves them together. It could, for example, integrate the underlying principles of the physics of sound - exploring wave properties like wavelength (**λ**), frequency (**ν**), and velocity (**V**), and their relationship **(λ*ν = V)** - directly with mathematical instruction and the complex melodic structures and microtonal nuances of Carnatic music. This integration allows a student to grasp not just what a musical piece is, but also the underlying physical and acoustic phenomenon that define its unique character, fostering a deeper, more holistic understanding that breaks down traditional subject silos. AI provides an incredibly fast way to instantaneously integrate diverse topics at the "speed of thought," adapting to a student's particular proficiency level, the classroom discussions, and the questions posed. This integrative approach ensures that the learning journey is fluid, contextual, and rich with real-world connections. Crucially, in the spirit of open science and education, every component of our classroom - including lecture videos, teacher's notes, digital textbooks, and student projects - is openly shared on our website and public repositories to serve as a blueprint for other digital learning environments. The complete pedagogical workflow is summarized in Figure 1.

2.2 Physical Environment and Hardware Configuration

Our pedagogical framework is designed with a specialized digital setup to balance high-tech capability with ergonomic safety and distraction-free learning. The teaching environment is centered around a shared computer station where the teacher and student sit together. The hardware setup includes:

- **Student Interface:** The student primarily interacts with the curriculum through an E-ink device. This choice is deliberate: E-ink screens provide similar reading behaviors as traditional paper print (Siegenthaler et al., 2011), are significantly better for eye health during long study sessions (Wang et al., 2023), and provide a distraction-free environment compared to high-refresh-rate LCD/OLED screens. We use either a 13.3" inch Onyx Boox Max Lumi E-ink device or a 13.3" Onyx Boox Tab X C color E-ink device, both of which are Android tablets equipped with a stylus.
- **Projected E-ink Tablet:** During class lectures, a primary E-ink tablet is attached to the computer. The teacher uses this device for handwriting notes and diagrams, which are then projected onto the main computer screen for the student to follow using a screen copy

tool (https://github.com/Genymobile/scrcpy). This replicates the intuitive feel of a traditional whiteboard while ensuring every stroke is digitized in real-time.

- **Recording and Documentation:** Every lesson is recorded using Open Broadcast Studio (OBS - https://obsproject.com/). This captures the desktop screen, teacher's notes, and oral explanations, creating a video library the student can refer back to for review. The digitized class notes are also saved on the tablet.
- **Computing for Technology Tasks:** While student's reading and writing occur on an E-ink device, the student utilizes a standard computer specifically for programming, technological exercises, and data-entry tasks.

2.3 Digital Workflow and Data Retention

The lifecycle of learning material is managed through a centralized cloud infrastructure using Google Drive, along with local backups and a Github repository.

1. **Note Generation:** Handwritten notes from the teacher and student are automatically saved to Google Drive.
2. **Resource Curation:** All reading materials, homework exercises, AI-generated study guides, class video lecture recordings etc. are stored in the same ecosystem, along with the student's works.
3. **Student Access:** The student has read access to all class materials and resources directly on his E-ink device, allowing him to perform his handwritten homework and study independently.
4. **Permanent Digitization:** By digitizing all homework, notes, and other projects from a young age, the setup ensures a permanent, searchable record of the student's entire educational progression. The database includes several hundreds of homework assignments, lecture notes, code repositories and hundreds of hours of class lecture video recordings that the student can refer to as needed.
5. **Open Access and Public Repository:** To ensure transparency and provide a resource for the broader educational community, all curriculum materials, projects, and logs are uploaded to our website and GitHub, accessible at https://nirmalavishwavidyapeetham.org/. For the interested reader, all figures, underlying code, animations, and other supporting materials for the use cases detailed in this study are also available here.

2.4 AI Integration: The Choice of Ecosystem

The classroom utilizes Google Gemini with Google AI Pro as the primary LLM assistant. Over the course of the Grade 1 and early Grade 2 period, we utilized versions 1.5, 2, 2.5, and 3, consistently opting for the latest or previous latest version available at the time to leverage the most current reasoning and contextual capabilities. This choice was driven by Gemini's tight integration with the Google Drive and Workspace ecosystem. While other AI tools may perform specific tasks with slightly higher or lower accuracy, the ability for the AI to read and summarize the student's

stored notes and textbooks within a single, secure environment made Gemini our preferred choice for this curriculum.

3. Results (Use Case Studies)

Table 1: Showcase of AI integrated visual projects

Use Case	Scope of Work	Learning Outcome	**Student Engagement**
Music and Waves	Decimal maths, Wave physics, Music theory, and Python-based visualization	Interdisciplinary synthesis of physics and art; public speaking via science presentations	Parameter manipulation to adjust wave properties and musical notes to generate wave animations and audio; Scientific presentation
Virtual 3D Globe & Mapping	Interactive Python-based 3D globe, geographical features, 2D map projections, and distortions	Intuitive grasp of spatial mathematics and global geography; awareness of AI fallibility	Navigated the interactive globe, adjusted coordinates, verified map scaling, generated images of desired locations
LaTeX Copy Tracing	Engineering custom 4-rule handwriting templates for English, Telugu, and Hindi scripts	Structural logic (content vs. format); technical typesetting workflow; motor skill development	*Creator/Author:* Chose fonts, authored practice books, and managed LaTeX macro compilation; Completed resulting handwriting exercises
Visual Sorting Algorithms	Animated visualization of sorting logic (Merge sort, Insertion sort, etc.) using Jupyter Notebooks	Intuitive grasp of sorting approaches and time complexity; kernel and cell execution mechanics	Transformed raw AI-generated text/code into functional Jupyter notebook blocks to visually learn sorting

In this section, we elaborate on the practical implementation of our framework through several interdisciplinary use cases where AI is tightly integrated into the student's daily learning. These case studies are categorized into two primary tracks: featured visual projects (Section 3.1), which detail the iterative development of interactive digital tools and 3D visualizations, and narrative use cases (Section 3.2), which focus on theoretical exploration, mathematical reasoning, and multilingual synthesis. Collectively, these examples demonstrate the student's transition from a passive consumer of information to an active digital architect and critical verifier, mastering concepts that traditionally span elementary to university-level curricula.

3.1 Featured visual projects

A defining characteristic of these featured projects is the iterative development process. The underlying code for each was first generated by the teacher using AI as an assistant, often requiring multiple cycles of AI interactions, development, and debugging to ensure accuracy and pedagogical value, with the student often playing the role of an observer. Once the base code was established, the student took an active role, playing around with the developed tools, changing parameters, and tailoring the results to his own interests, taking more ownership as the curriculum progressed. A summary of these visual projects is presented in Table 1.

3.1.1 Music and Waves (Physics, Mathematics & Art)

This project (described in Figure 2) served as a cornerstone for multidisciplinary learning, bridging the gap between abstract physics, mathematics, and tangible artistic output. Furthermore, the student's ongoing Carnatic music practice inherently supports advanced mathematical skills, particularly in the understanding of patterns, ratios, and complex rhythmic structures (Raja and Bhalla, 2021).

- **Foundational Learning:** The project began with a study of wave physics, exploring the relationships between amplitude **(A)**, frequency **(ν)**, wavelength **(λ)**, velocity **(V)** and attenuation factor **(f)** (Urone et al., 2020). Simultaneously, the student learned and practiced decimal multiplications in mathematics and this project provided a real-world application to calculate varying wave properties, as given by the relationship **λ*ν = V.**
- **Programming Concepts:** Before diving into the code, the student was introduced to the concepts of functions and parameters in the course on Programming and Algorithms, understanding how inputs drive specific outputs in a digital system (Spronck 2024; Das et al., 2024).
- **Teacher-AI Iteration (Visuals):** The teacher utilized AI to develop a Python script capable of generating wave animations based on these parameters. This required several iterations to ensure the visualizations accurately represented the mathematical relationships. Crucially, the student observed the teacher correcting the AI's initial mathematical errors, reinforcing the idea that AI-generated code requires human oversight.
- **Student Interaction:** The student "played" with these functions, inputting different decimal values to see how the wave's shape transformed. This exploration allowed the student to

verify the physics they had learned (e.g., observing how wave length (**λ**) decreases as the frequency (**ν**) increases when moving from note C3 to F#3 on a flute or a piano).

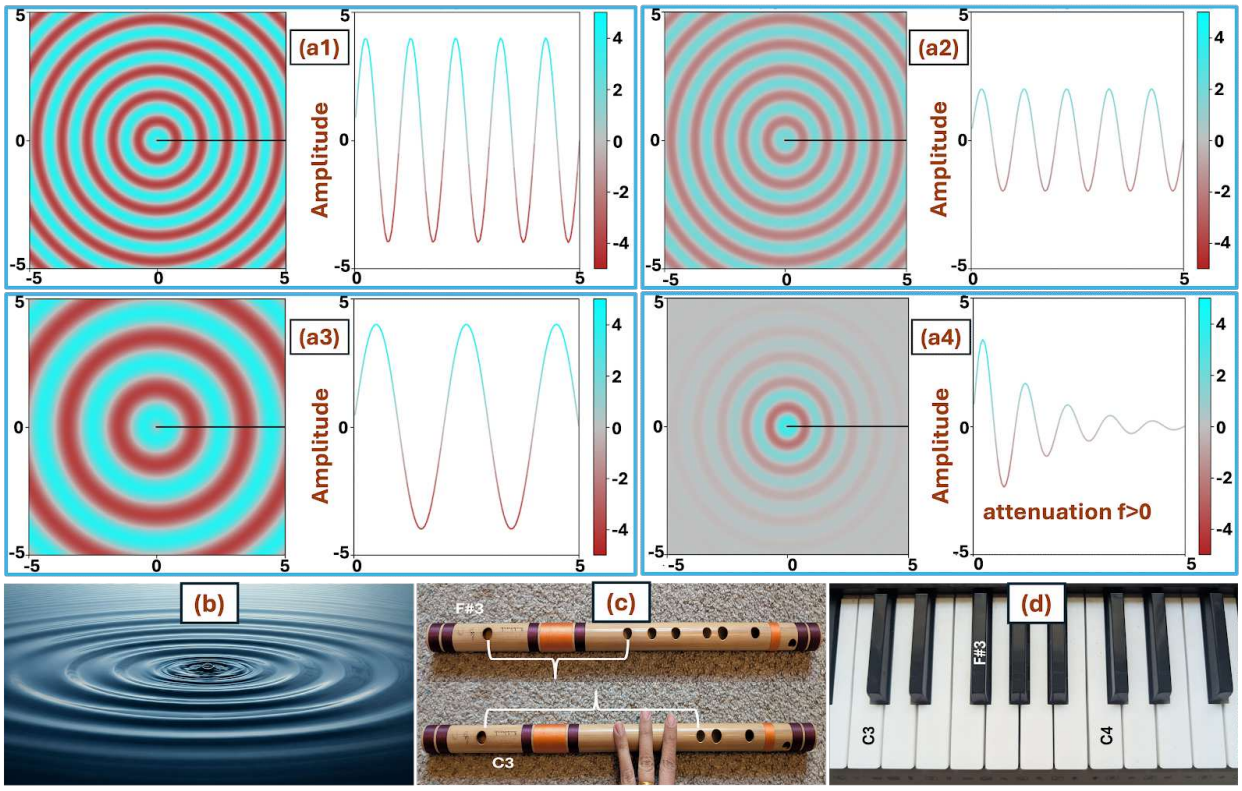


Figure 2. Music and Waves: *(a) A Python based animation project that demonstrates moving waves on water surface, originating from a central source as shown in (b). (a1-a4) show snapshots of the animations at specific moments in time. These images illustrate how the wave properties - specifically, the wavelength (λ), frequency (**ν**), amplitude (A), and the attenuation factor (f) - influence the wave's appearance, while the velocity (V) remains fixed. In each of these images, two dimensional projections of the circular surface waves are shown on the left, while a one dimensional projection of the amplitude (height/depth) of the waves along a radius are shown on the right. Starting from a reference point for the wave properties in (a1), reduced amplitude (A) is demonstrated in (a2), increased wavelength λ and decreased frequency **ν** as given by their relationship λ***ν** = V are shown in (a3), while (a4) shows a higher attenuation factor where the wave amplitude gradually reduces over time/distance. (c) As we move from the note F#3 to C3 on a flute, the gap between the embouchure hole (blow hole) and the first open hole increases, thus increasing the wave length (λ) and decreasing the frequency (**ν**). (d) On a piano, the same transition from F#3 to C3 happens from right to left, decreasing the frequency. In these instruments, the amplitude (A) controls volume, while the velocity (V) doesn't change for sound waves traveling in air. The attenuation factor (f) is higher for a piano than harmonium, thus attenuating faster. The student achieves a comprehensive understanding of these wave properties through interactions with these simulations.*

- **Algorithmic Music Generation:** Following the visualization phase, a separate piece of code was introduced to programmatically generate music. The teacher refined this code via AI

to handle musical notes as inputs. The student then acted as the primary user, inputting notes for several songs learned in their Carnatic music class (Jagannadhamu 1951). By manipulating the function parameters, the student was able to generate music programmatically and hear their repertoire synthesized through the computer.

- **Science Fair Presentation and Social Skills:** To conclude the project, the student presented their findings at a science fair. The presentation featured a large-format poster made by the student and a laptop setup to play the programmatically generated music. Explaining the connection between wave physics and musical notes to fair visitors allowed the student to develop critical social skills and public speaking confidence.

3.1.2 Mapping Latitudes and Longitudes (Geography & 3D Visualizations)

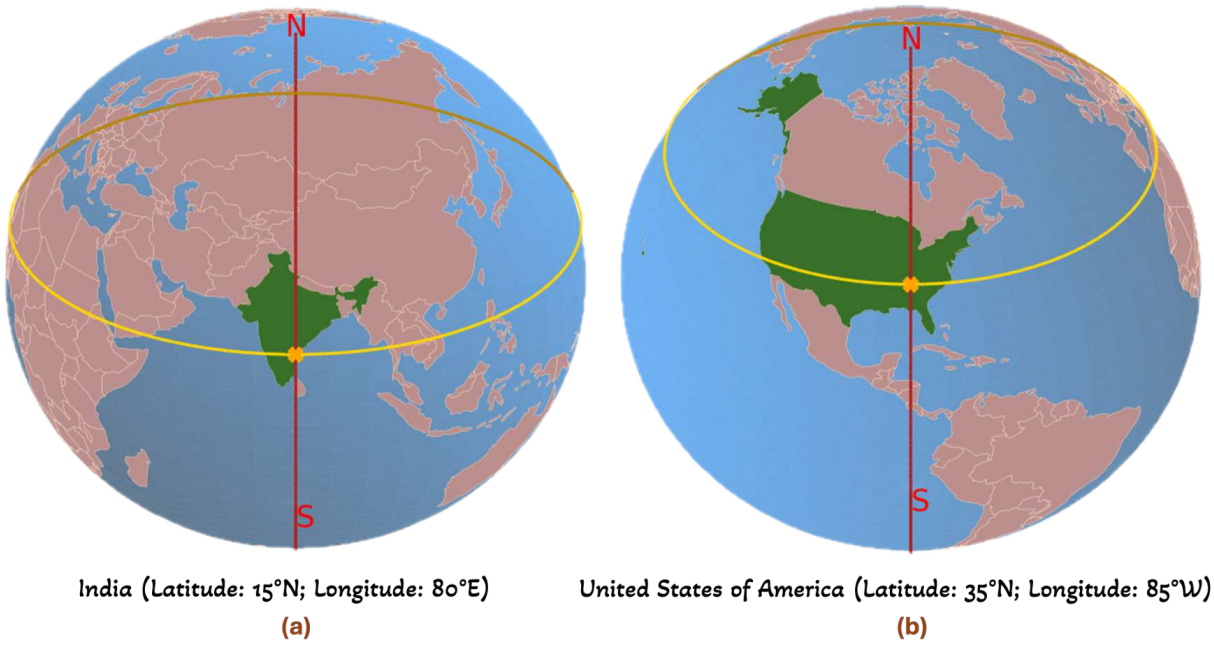


Figure 3. Virtual Interactive Globe: *A Python-based project designed for the visualization of a 3D virtual globe, enabling students to interactively manipulate the location of interest by modifying latitudes and longitudes or by rotating the globe along vertical and horizontal axes. The visualization is intended to be a quick learning tool simulating a physical globe while simultaneously displaying real-time latitude and longitude data and highlighting regions of specific interest as shown in (a) for India and (b) for the United State of America.*

This project evolved from a standard geography lesson into a sophisticated exploration of spatial mathematics and interactive visualization as shown in Figure 3.

- **Project Origins:** The initial goal was to learn about different countries and basic geography. However, the teacher observed that standard 2D maps often provided misleading impressions regarding country size and distances due to inherent distortions (Robinson and Kimerling 1969).
- **Learning Map Projections:** Using AI-generated explanations, the student explored how map projections (like the Mercator, Gall-Peters, and Winkel Tripel) attempt to solve the "orange

peel problem" - flattening a 3D sphere onto a 2D surface. This led to a deeper understanding of geographic coordinates, such as the Equator, Prime Meridian, and the Tropics.

- **Teacher-AI Iteration (Virtual Globe):** The teacher used AI to develop a specialized Python tool. The primary objective of this code was pedagogical clarity - specifically teaching the relationship between latitudes and longitudes - rather than achieving high computational efficiency, visual polish, or geographic precision. While the development of this tool took a couple of hours of iteration, it remained a reasonable time investment that allowed the teacher to create a functional, interactive display tailored precisely to the lesson's needs. Crucially, the mathematics underlying the complex sphere-to-plane projections (like trigonometry and vector algebra) were intentionally omitted from discussion at this stage, with the plan to revisit the project in future grades to connect the visual learning to the formal mathematical concepts.
- **Verification and Trust:** Throughout the development process, the student observed the teacher identifying and correcting several AI-generated errors, such as misaligned coordinate markers and incorrect map scaling. This provided a crucial lesson in critical thinking: the student learned not to trust AI for all the details and understood that the tool is a fallible assistant that must be cross-checked against authoritative geographical sources.
- **Student Interaction:** The student used the tool to "explore" the Earth, with the ability to rotate the globe horizontally and vertically and dynamically adjust latitudes and longitudes. This hands-on approach made the abstract concept of a global coordinate system feel intuitive and visual.
- **AI-Generated Assessment:** To reinforce and consolidate the entirety of this learning journey - from 2D distortions to a 3D coordinate system - the teacher used AI to generate a comprehensive final quiz. This assessment covered oceans, continents, and specific projection characteristics, which the student answered after mastering the study material and the interactive globe.

3.1.3 LaTeX Copy Tracing (Language & Fine Motor Skills)

While the student demonstrated language proficiency across English, Telugu, and Hindi, the teacher identified a need for more structured handwriting practice. After finding online copy-tracing resources to be too generic and inflexible, the team decided to design a custom solution for generating high-quality practice templates.

- **Design Requirements:** The goal was to create sheets where each line of text features a four-rule background. These horizontal rules highlight specific character segments: the top part (ascenders), the middle section, and the bottom segments (descenders). Because character proportions differ between Latin and Brahmic scripts, the vertical positioning of these rules and the gaps between them had to be dynamically adjustable for each language. Each page followed a structured layout: a clear template line at the top, several lines of low-opacity (transparent) text for tracing, and finally, empty ruled lines for independent practice.

- **Technical Evolution (Python to LaTeX):** The project initially attempted to use Python libraries for rendering. However, AI-generated Python code struggled to manage the precise geometric overlays and complex multilingual font rendering required. The teacher pivoted to LaTeX - a tool they were familiar with for manuscripts but had never used for complex graphical macros (Kopka and Daly, 2003). Through a series of back-and-forth prompts with AI, they successfully built a LaTeX project using custom rule generation macros as demonstrated in Figure 4.

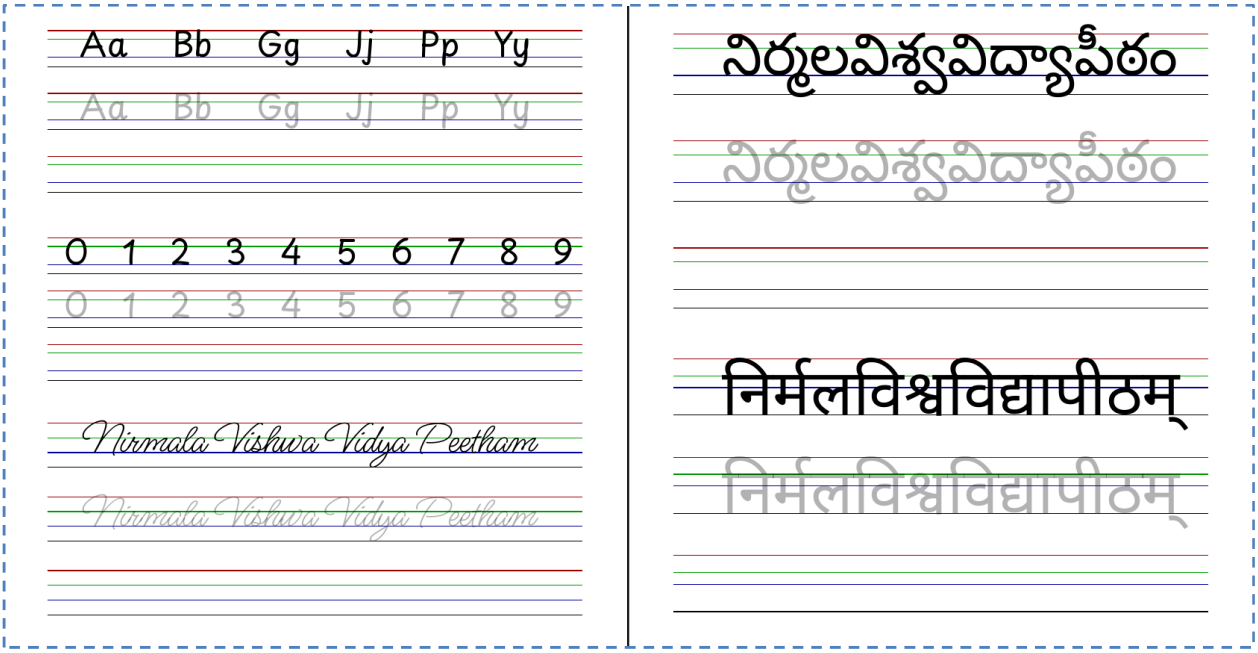


Figure 4. LaTeX Copy Tracing: *A LaTeX-based project enabling students to author complete copy-tracing books, utilizing text of their own selection for writing practice in English, Telugu, and Hindi. The foundational rules and lines, accommodating various character features such as ascenders and descenders, are fully customizable. Each page features a bold text line containing the source text at the top, followed by several lines with transparent text for the student to trace, and concluding with empty lines for independent practice. These elements are all adaptable to cater to the distinct character settings of different languages.*

- **Student as Creator:** Once the project was stable, the student transitioned from learner to creator. He learned the fundamentals of LaTeX editors, and code compilation. Using openly available Google fonts (https://fonts.google.com/) - such as "Playpen Sans" for print and "Ms Madi" for cursive - the student authored entire copy-tracing books with text of his own choosing for English, Telugu, and Hindi languages, customizing the page layouts and the spacing of the four-rule background according to the specific requirements of each language. Through this process, the student gained a better understanding of LaTeX code, its usage, macros, and debugging.
- **Outcome:** This project transformed a mundane fine-motor task into a lesson in software

environments, typography, fine arts, and authorship. This customization made the repetitive task of handwriting practice significantly more engaging. The student gained a sense of ownership over his learning materials while simultaneously mastering the technical workflow of professional typesetting.

3.1.4 Sorting Algorithms: A Visual Approach

After mastering foundational programming concepts such as data types and loops, the curriculum transitioned to the study of algorithms (Bible and Moser, 2023). To introduce the advanced topic of sorting to Grade 1 and 2 students, we focused on an interactive and highly visual approach using Jupyter Notebooks (Toomey 2016) .

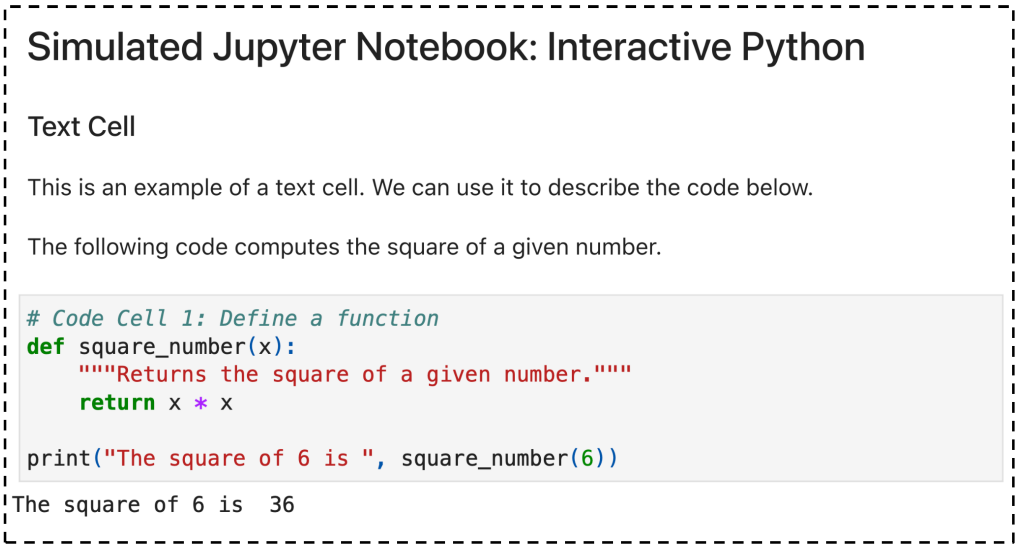


Figure 5. Interactive Python: *An interactive Jupyter python notebook where students can study a concept (in a text cell) and immediately execute the corresponding code (in a code cell) to see the resultant output.*

- **The Learning Environment:** Jupyter Notebooks were selected because they provide an interactive lab environment where students can study a concept and immediately execute the corresponding code to see the output as shown in Figure 5. Before tackling algorithms, the student used AI-generated tutorials to learn the basics of the notebook environment, including the distinction between markdown cells for documentation (text) and code cells for logic.
- **Visual Methodology:** Because sorting is an abstract concept, the teacher worked with AI to generate visualizations using bars of various sizes to represent data values, as shown in Figure 6. This allowed the student to see the swapping and comparing of data points in real-time as the algorithms progressed.
- **Student as Transformer:** A significant learning outcome occurred during the assembly of the project. While the AI initially provided the explanation and visual code as a single, flat text file, the student was tasked with transforming this raw output into a functional Jupyter

notebook (.ipynb file). This required the student to manually partition the content into separate text and code blocks, integrate data tables for complexity analysis, and manage the notebook's internal state.

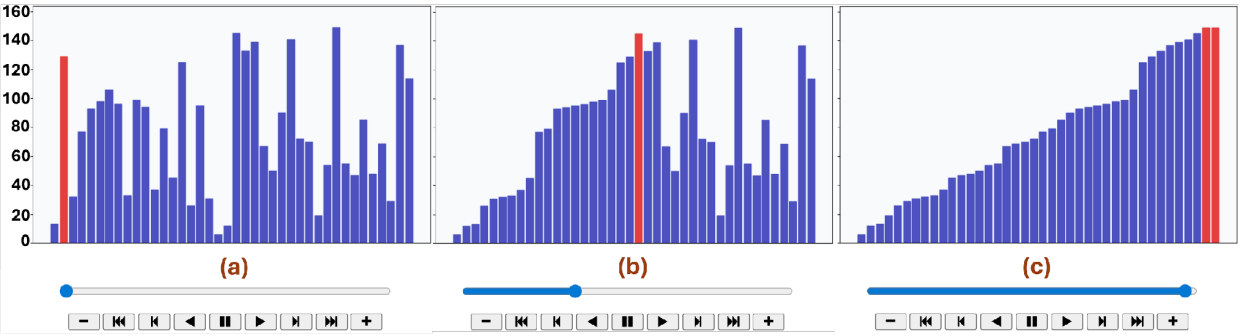


Figure 6. Sorting visualized: *A visual demonstration of sorting algorithms is presented utilizing Jupyter Python notebooks. Only selected snapshots of the output animations are included herein: (a) illustrates the initial unsorted dataset, (b) displays a partially sorted dataset, and (c) represents the final sorted result. Students are able to interact with the animated output for each algorithm and navigate the steps both forwards and backwards using the control panel, thereby facilitating a detailed comprehension of various sorting algorithms.*

- **Analysis and Outcome:** The student learned the mechanical workflow of managing Python kernels and cell execution while using the visualizations to understand the step-by-step logic of Insertion Sort, Selection Sort, Bubble Sort, Merge Sort, and Quick Sort algorithms. By watching the bars rearrange themselves, the student gained an intuitive grasp of why certain algorithms are fundamentally faster than others, transforming a complex computer science topic into a tangible, observable experience.

3.2 Narrative Use Cases (Text-Based)

This section focuses on the narrative use cases, which represent a significant area of theoretical and practical exploration for the proposed AI-driven educational framework. These use cases are designed to go beyond simple content delivery and delve into more complex, cognitive-heavy applications. Specifically, they encompass and focus on three major dimensions: the theoretical exploration of complex concepts, the application of sophisticated mathematical and logical reasoning to problem-solving, and the capacity for seamless multilingual synthesis of information, as summarized for clarity in Table 2.

- **Spontaneous Teaching Workflow:** Whenever needed during a lesson, the teacher elaborated a rough teaching plan to the AI and requested a detailed, structured document for the student to refer to later. This allowed for the rapid creation of professional-grade reading material and interdisciplinary integration that would traditionally be time-consuming to source from textbooks.

Table 2: Showcase of AI integrated narrative use cases

Use Case	Scope of Work	Learning Outcome	**Student Engagement**
Multilingual Literature	Simplification of classical Telugu/English texts; Age 15 level vocabulary challenges.	Vocabulary expansion; cross-cultural literary appreciation; lyrical interpretation.	Verifier: Identified factual hallucinations and improved sentence construction.
Advanced Maths & Theory	Fractions, GCF/LCM, cyclicity patterns, and Roman numeral conversion logic.	Mastery of advanced number theory; bridge from mental arithmetic to word problems to Python automation.	Solver & Auditor: Solved high-volume problem sets and audited AI-generated grading logic.
Algorithmic Logic	Study of markup languages, control structures, Greedy algorithms, and Binary Search.	Understanding of algorithmic optimality; mastery of boolean logic and operator precedence.	Designer: Built failure-case coin change systems and analyzed logarithmic vs. linear complexity.
Research & Science	Study of the scientific method, peer review, and distilling professional scientific papers.	Understanding the professional research ecosystem and the reproducibility crisis.	Analyst: Distilled "essential stories" from technical papers and employed the scientific method for simple experiments.
Admin & AI Literacy	Use of AI to transcribe notes, summarize videos, and generate/grade iterative exams.	Meta-cognitive awareness of curriculum progression; high-level AI literacy.	Critical Reviewer: Identified and corrected the mistakes in AI-generated quizzes/solutions/grading

3.2.1 Multilingual Literature, Music Theory, and Iterative Assessment

This section explores how AI was utilized to bridge language gaps and create age-appropriate curriculum content from advanced, open-source resources.

- **Telugu Literature and Language Integration:** We utilized AI to summarize complex chapters from Telugu textbooks, such as the life of Shri Gautama Buddha (Rajannakavi 2015) and the stories of Tenali Ramakrishna (Sundaramma 1991). Because the original texts were written for an advanced audience, AI was used to generate simpler, age-appropriate supplementary versions in Telugu alongside English translations. This dual-language approach allowed the student to master both languages simultaneously, as a core task required the student to translate texts or summaries between English and Telugu for skill development. However, during this process, we identified issues with AI-generated Telugu sentence construction and factual hallucinations. The teacher worked closely with the student to go over the output, correcting errors and improving the text where needed. This proved to be a valuable exercise for developing language skills.
- **On-the-Fly Curriculum Adjustment:** AI enabled dynamic responses to classroom needs. For example, during a discussion where it was discovered the student was unfamiliar with the Telugu names for seasons, we used AI to immediately generate a study document covering seasons, months, days, and weeks.
- **English Literature and Vocabulary Development:** Various classroom readings and other material, including notable lectures on meditation, were summarized using AI. Initially, summaries aimed at a 5 or 6-year-old level were found to be too simplistic to facilitate literary growth. By adjusting the methodology to prompt for "Age 15 level" summaries, we obtained professional, structured language that challenged the student and expanded their vocabulary without being incomprehensible.
- **Music Theory and Lyric Interpretation:** In Indian Carnatic Music studies, AI translated chapters from the Telugu textbook (Jagannadhamu 1951) into English as the class progressed. Furthermore, for songs composed in ancient Telugu and other Indian languages, AI provided word-for-word meanings and translations. This ensured the student understood the profound lyrics in addition to learning the musical notes.
- **The "Verifier" Model of Assessment:** Several assessments were conducted through AI-generated quizzes. A core pedagogical objective was teaching the student that AI is fallible. Quizzes often contained errors in question logic or facts; the student's job was to identify and correct these flaws while providing their answers. Following submission, AI was asked to grade the student's responses and the student was then tasked with checking the AI's grading, identifying instances where the AI was mistaken. Final results were verified by the teacher, demonstrating how to use AI as a useful but fallible assistant.

3.2.2 Mathematical Problem Solving and Logical Reasoning

AI was utilized to spontaneously bridge the gap between simple arithmetic and complex number theory, providing professional-grade study materials and rigorous practice sets.

- **Fractions and Number Theory Progression:** The curriculum used AI to provide real-world

examples of fractions (e.g., in cooking and measurements) and explain operator precedence (Marecek et al., 2020). AI generated word problems that integrated these concepts, allowing the student to see the practical utility of mathematical order. Learning simplified fractions led naturally to Greatest Common Factor (GCF) and Least Common Multiple (LCM). These concepts were further supported by AI-guided lessons on prime factorization and divisibility rules (tricks for identifying numbers divisible by 2, 3, 4, 5, 6, 9 etc.).

- **Patterns and Combined Logic:** The ideas presented in divisibility rules were further extended to finding the last digit of high powers (e.g., 34^{47}) through cyclicity patterns. The teacher described the underlying cyclic patterns, and AI was then used to generate combined exercises where divisibility rules and power patterns were to be solved simultaneously, a level of integration that would be difficult to find in standard elementary workbooks.
- **The Roman Numeral Lifecycle:** AI was used to describe the rules for Roman to decimal conversion (or vice versa), which the teacher corrected and explained. To reinforce mastery, AI was used to provide the student with a high volume of practice material (200 problems) that would have been tedious for the teacher to produce manually. After the student completed them, AI was asked to provide solutions and grade the responses. The student then verified the AI's grading, identifying his own mistakes as well as instances where the AI was in error. Finally, the student wrote Python code for the conversion and compared his implementation with an AI-generated solution.
- **Vetted Professionalism:** A recurring theme was the use of AI to generate professional-grade reference texts and homework exercises spontaneously during class. These materials were only added to the student's study documentation after rigorous teacher verification, ensuring they remained accurate and age-appropriate.

3.2.3 Programming, Algorithmic Logic, and Technology

This section details how AI supported the introduction of high-level computer science logic and technological literacy to young learners through interactive explanations, spontaneous interdisciplinary integration, and hands-on implementation.

- **Technology Fundamentals:** AI served as a resource for general technological literacy, explaining the functions of different Operating Systems (OSs) and the professional application of office software (e.g., Microsoft Excel, Google Docs) and other applications. To highlight an example of our integrated approach, before beginning the visual projects detailed in Section 3.1, the curriculum used AI to establish a foundation in digital document engineering. This phase focused on understanding markup languages like LaTeX, Markdown, and HTML. The goal was to teach the core logic of digital documentation - specifically the separation of content from formatting - prior to practical implementations such as copy-tracing books or Jupyter notebooks.
- **Core Programming Structures and Logic:** AI was used to explain fundamental building

blocks, including lists, if-else statements, and loops. The curriculum explored structural logic deeply, with AI explaining how to convert “while” loops to “for” loops (and vice versa) through comparative examples and practice exercises. More advanced topics included dictionaries, structures, classes, and file operations. AI was also instrumental in teaching logical/boolean operator precedence and in combining arithmetic, relational, and logical operations. The student practiced simplifying boolean expressions and creating truth tables through AI-generated exercises.

- **Debugging and Best Practices:** To cultivate engineering discipline, AI was used to explain the process of debugging code. This included teaching the student about step-by-step execution, setting breakpoints, and identifying and explaining logical errors in their implementations.
- **Interdisciplinary Practical Integration:** A defining feature of the curriculum was that every mathematical concept learned or practiced - from on-paper arithmetic to complex number theory - was immediately integrated with programming. The student was tasked with implementing these algorithms in Python, creating a fully integrated interdisciplinary practical curriculum where mathematics and coding were presented as two sides of the same logical coin. For instance, algorithms for the Greatest Common Factor (GCF) and Least Common Multiple (LCM) were implemented to automate the simplification of fractions. As another example, the student acquired proficiency in converting binary numbers to any other base and vice versa.
- **Case Study: Greedy Algorithms and the Coin Change Problem:** This exploration of algorithmic strategies began organically with the study of loops. We used AI to generate word problems focused on iteration, and one of the initial problems was the "coin sum" problem: finding the minimum number of coins needed to make change for a given total. The student's initial attempt often naturally led to a "Greedy" approach - an algorithm that always makes the locally optimal choice at each stage by selecting the largest coin denomination possible. During review, the teacher pointed out that while the greedy solution works for the standard US currency system, it is not a universally optimal strategy. Using AI, we elaborated on this finding and analyzed why the greedy algorithm fails in certain hypothetical systems. For instance, in a system with 1, 5, and 12-cent coins, making change for 15 cents using a greedy approach would yield 4 coins (12 + 1 + 1 + 1), whereas the optimal solution is 3 coins (5 + 5 + 5). This progression - from an initial problem on loops to a deeper analysis of algorithmic optimality - fostered a significant learning moment. The student was then challenged to design his own hypothetical coin systems where the greedy approach would fail, fostering a deeper understanding.
- **Case Study: Bisection Method vs. Binary Search:** Another example of such crossdisciplinary investigation occurred while studying exponents and roots. First, the student studied the “Bisection Method” in class to compute roots for non-perfect powers (e.g., the square root of 20). The teacher then identified a strong structural similarity between this method and the “Binary Search” algorithm in programming. We used AI to summarize both concepts together. This was followed by a lesson on “Linear Brute Force Search” in programming,

which prompted the student to think about the parallel linear search for roots - calculating the root by checking every small increment (e.g., 4.01, 4.02... up to 5.00 for a precision of up to two decimal places) - and realizing its extreme inefficiency compared to the halving logic of bisection. AI was used again to summarize the entire interdisciplinary comparison, producing reading material on logarithmic vs. linear time complexity that synthesized maths and programming in a way rarely found in standard texts.

- **Complex Implementation:** AI assisted in developing the more complex projects described in Section 3.1, such as generating wave images and movies, programmatically playing music, creating a 3D interactive globe, or building math-based games.

3.2.4 Social Studies, Science and Research Reproducibility

This section describes how AI facilitated a deep dive into the scientific method and the mechanics of academic research, alongside foundational curriculum summaries and interdisciplinary projects.

- **Textbook Summarization:** AI was used to synthesize and filter standard textbook chapters in science (e.g., *Plants around us*, *Animals around us*, *Body Parts*, *Food*, and *Water*) and social studies (e.g., *Family*, *Travel*, *Communication*, *Games and recreation*, and *Directions*). Once all textbook exercises were thoroughly read and completed, we leveraged AI to identify and extract the core material essential for long-term memorization. This efficient, multi-stage workflow freed up valuable classroom time, enabling the student to then engage in advanced investigations.
- **The Scientific Method and Professional Research:** We used AI to explain the Scientific Method through practical examples and testing procedures, such as investigating solar patterns (when/where the sun rises or sets and how it affects our day-night cycle). The student studied the professional ecosystem of science, including how research projects are structured, how papers are written, the peer review process, the role of scientific grants, and the importance of openly sharing research data. All of this was instrumental in allowing the student to contribute to the current study.
- **Reproducibility and Open Science:** A significant focus was placed on the "reproducibility crisis." AI was used to explain why research must be documented precisely for replication, the ethical implications of data transparency, and the benefits of Open Access publishing.
- **Distilling Complex Literature:** AI enabled the student to interact with high-level academic papers that would normally be inaccessible. For example, we distilled the essential story from technical papers on Black Hole Fuzzballs (Skenderis & Taylor, 2008) and The Amygdala and Emotion (Gallagher & Chiba, 1996). Using AI to explain these at a "15-year-old level" - as established for English literature studies to maintain a balance of literary sophistication and accessibility - the student could engage with technical jargon and cutting-edge concepts.

- **Practical Skills and Etiquette:** AI supported the development of presentation skills by generating presenter notes for the student's "Music and Waves" science fair poster (Section 3.1.1). Furthermore, AI facilitated a comparative study of "Good Manners,"

contrasting social etiquette in Indian and US cultural contexts to provide a nuanced global perspective.

- **Advanced and Interdisciplinary Investigations:** Consistent with the featured visual projects (Section 3.1), we conducted several advanced projects using AI in social and scientific contexts. These projects often blurred the lines between disciplines, applying computational logic to scientific questions or using artistic visualizations to explain physical phenomena.
- **Assessment:** AI created customized homework exercises across all these topics, ensuring that the student reinforced his understanding through constant practice and iteration.

3.2.5 Classroom Administration, Preparation, and AI Literacy

This section describes the operational and pedagogical role of AI in managing the classroom and fostering early AI literacy.

- **Administrative and Preparatory Efficiency:** We utilized AI to transcribe and summarize handwritten class notes and to generate/process subtitles from class discussion videos. This enabled the rapid creation of study materials and homework exercises. AI was also used to summarize all the material learned in a specific subject to provide the student with a high-level overview of the curriculum when needed. All subject material and homework exercises were individually tuned and iteratively adjusted based on the student's level of understanding and progression through various topics.
- **Assessment and the "Verifier" Model:** AI was used for creating and grading exams. However, a defining feature of our assessment model was that the student was frequently tasked with identifying and correcting mistakes made by the AI. This included finding errors in AI-generated questions, refining incorrect AI-suggested answers, or challenging the AI's grading logic. Final results were always verified by the teacher.
- **Developing AI Literacy:** While the student did not use AI tools independently for safety and focus reasons, this integrated workflow allowed him to develop a nuanced understanding of the pros and cons of LLMs. He observed firsthand how AI tools were constantly changing and learned to identify the limitations of the technology, such as its propensity for hallucination.

4. Discussion: The AI-Augmented Pedagogical Framework

The case studies presented illustrate a shift from traditional rote learning to an AI-integrated environment that prioritizes interdisciplinary synthesis and critical verification.

4.1 Expanding the Boundaries of Traditional Education

The primary advantage of this integrated digital model is its ability to facilitate projects that would otherwise be impracticable in a traditional elementary classroom. Concepts typically reserved for advanced levels - such as wave physics, algorithmic complexity, or studying scientific literature - become accessible when AI acts as an interpretive bridge. By distilling

technical jargon from academic papers (e.g., the Black Hole Fuzzball or Amygdala studies) into sophisticated yet accessible language, the essential stories of advanced scientific literature become accessible to students who can engage directly with the frontier of human knowledge. The use of early childhood projects as a primary data source offers a unique advantage: it makes the underlying logic of AI application accessible across disciplines. By demonstrating how LLMs can bridge university-level physics for a six-year-old, the framework provides a transparent blueprint for information fusion that is directly transferable to adult learners.

4.2 "Speed of Thought" Preparation and Synthesis

For the educator, AI serves as an intellectual exoskeleton, allowing lesson preparation to occur at the "speed of thought." A recurring theme throughout this study is that when learning complex but related topics, AI provides an incredibly fast way to integrate them. Curating integrated reference texts from disparate fields - such as programming and mathematics (e.g., the Bisection/Binary Search project), or physics and music with programming - would traditionally be a tedious manual task. AI saves a significant amount of time by curating these integrated versions spontaneously, enabling a "Curriculum of One" that adapts in real-time to the student's specific questions and proficiency levels.

While the material covered is significantly more advanced than a typical early childhood curriculum, the average teacher time required for curation and direct instruction of new subject material was minimal. This efficiency shifted the pedagogical focus, allowing more time for the student to engage in practice exercises, project-based learning, and activities with practical utility. Without AI, maintaining this level of academic depth would have been exponentially and prohibitively time-consuming. In a traditional school setting, AI integration could allow teachers to manage multiple students while still providing highly detailed, personalized training plans tailored to individual strengths and weaknesses. Consequently, this same efficiency enables well-educated parents to provide rigorous educational oversight and organizational management of their child's development with minimal daily time investment.

4.3 The Critical Role of the "Teacher-Verifier"

Our findings underscore that AI cannot be used as a primary source due to its inherent lack of trustworthiness on several topics. A successful AI-integrated classroom requires the teacher to be deeply knowledgeable in the subject matter beforehand to distinguish between accurate output and hallucinations (Anh-Hoang, 2025).

- **Vetted Requirements:** All AI-generated code and text must be vetted.
- **The Reproducibility Parallel:** Interestingly, teaching the "reproducibility crisis" in science provided a perfect parallel for teaching AI literacy. The student learned that even authoritative-looking sources, whether a peer-reviewed paper or an LLM response, require verification. This fosters a universal skepticism and rigorous critical thinking that is essential for the digital age.

4.4 Adapting to the Exponential Pace of Change

Just as AI has revolutionized software development by creating an exponentially faster environment for prototyping, it is currently having a similar effect on the educational landscape. The tools and models used in these case studies are not static; the rapid improvements in LLM reasoning capabilities mean that the shortcomings identified today may be solved within months. In such an environment, the goal of education shifts: rather than mastering a static set of facts, students must learn to be agile verifiers who are comfortable with the idea that their tools will be significantly more capable by the time they reach higher grades.

4.5 Breaking the Silos: The Integrated Practical Curriculum

A major insight from this study is the dissolution of subject silos. By immediately implementing mathematical concepts (like GCF or Roman numerals) through Python code, the student stops viewing maths and programming as separate subjects. They become two sides of the same logical coin. AI facilitates this integration by providing the "interpretive tissue" between theoretical concepts and functional code, allowing for a fully integrated practical curriculum. The efficiency gained through this highly personalized, AI-integrated curriculum is not solely dedicated to accelerating academic progress; a crucial outcome is the creation of substantial time for the student to engage in holistic, extracurricular development, including sports, fine arts, meditation, and external community events.

4.6 AI-Proof Assessment Strategies

As access to LLMs becomes ubiquitous, traditional assessment formats require a radical redesign. Most students today have ready access to AI, and we should assume they will use it. Educators must therefore design exam strategies from the perspective of an AI-equipped student, tailoring assessments to test genuine mastery rather than rote retrieval. This shift is critical to prevent the accumulation of "Cognitive Debt" - where the ease of AI-assisted generation prevents the development of deep structural understanding (Kosmyna et al., 2025; Bastani et al., 2025).

- **Project-Based Evaluations:** The focus should shift toward complex, open-ended projects similar to the visual projects detailed in Section 3.1. In this model, students are encouraged to use AI as a tool, but the grading criteria prioritize the student's ability to modify, extend, and troubleshoot to engineer the desired outcome. The goal is to move from submitting an answer to defending a solution.
- **Oral and Defense-Style Assessments:** Incorporating oral exams or presentations modeled after a dissertation defense is a robust way to verify internal understanding. By asking spontaneous, deep-dive questions about the logic behind a project or a piece of code, teachers can ensure the student possesses a deep grasp of the material regardless of the tools used to assist them.
- **The Critical Correction Format:** Instead of standard multiple-choice questions, exams can utilize a "Verifier" model. Students can be given AI-generated answers that contain factual

or logical errors and be tasked with identifying and fixing them. In higher education, this logic could translate to university students verifying AI-generated research summaries or graduate-level engineers auditing auto-generated code. This format serves as a vital pedagogical bridge to broader information literacy. By training the student to scrutinize machine-generated content, the "Verifier" model could serve as the foundation for critically evaluating misinformation in contemporary or historical contexts.

4.7 Cultivating Social and Cultural Intelligence

Finally, AI's ability to conduct comparative studies facilitates the early development of cultural intelligence. Given the student's own multicultural background, we utilized AI to analyze differences in cultural practices across various societies. Specifically, we examined what is considered "good manners" in different contexts - such as contrasting Indian and US social etiquettes - to understand the underlying values and historical reasons for these norms. This enables the student to explore the "why" behind social expectations, bridging the gap between local traditions and global citizenship while fostering a sophisticated understanding of a pluralistic world.

4.8 The Infrastructure of Learning: Storage and Longevity

The success of this pedagogical model relies heavily on its digital infrastructure. By utilizing an E-ink-to-Cloud workflow, the curriculum overcomes the limitations of physical paper:

- **Permanent Retention:** All homework, notes, and projects are digitized from Grade 1 onwards, creating a lifelong data repository of progress.
- **Seamless AI Retrieval:** The tight integration of cloud infrastructure and AI allows us to "remember" and spontaneously reference a student's past work and adapt the curriculum, which is a significant advantage over using disconnected tools with inaccessible historical context. Future work in this area should explore how multi-modal AI agents could further automate the organization and cross-referencing of these lifelong learning records (Sapkota et al., 2026; Fei et al., 2024).

4.9 Shortcomings, Cautionary Notes, and the Evolving AI Landscape

Despite the transformative potential of LLMs, our case study identified several critical shortcomings that necessitate a cautious pedagogical approach. A primary challenge is the phenomenon of hallucination, where AI occasionally omits crucial details or invents plausible but incorrect facts. Furthermore, LLMs frequently experience context confusion when tasked with summarizing or querying large volumes of text. We found that asking questions about a specific chapter often triggered the inclusion of irrelevant topics from elsewhere in the textbook, making it essential to process data chapter-by-chapter to keep context windows within reliable limits.

From a technical perspective, AI outputs often lack reproducibility. The same prompt provided

under different contexts, or even to the same model at different times, often fails to reproduce identical results, with the system making new and different mistakes in each instance. This instability highlights a significant expert dependency: the teacher must remain deeply knowledgeable in the subject matter to serve as a corrective authority, as AI cannot yet be trusted to serve as a standalone textbook.

These limitations were particularly evident in algorithmic and mathematical tasks. In a separate project to solve a classic single player puzzle game (Peg Solitaire or Brainvita*)*, the AI struggled to visualize or solve complex logic correctly compared to existing specialized open-source projects. Additionally, while the initial generation of code is highly efficient, we found that manual debugging was often faster and more accurate than iterative prompting through AI. Mathematical computations, similarly, often required manual verification due to the frequent inaccuracies inherent in current LLM logic.

The AI landscape itself is in a state of exponential and overwhelming flux. The sheer volume of competing systems - including OpenAI (GPT series/ChatGPT), Google (Gemini series), Microsoft (Copilot), Anthropic (Claude series), Meta (Llama series), and xAI (Grok) - makes it nearly impossible for educators to track every new iteration. To date, our framework has utilized basic generative AI tools, primarily chat-based interfaces for text and code generation. But the field is rapidly pivoting toward Agentic AI, which refers to autonomous systems capable of independently setting goals, planning, reasoning, and executing multi-step tasks with minimal human intervention, acting proactively rather than merely reactively. While we have not yet integrated agentic capabilities into our homeschool setup, their potential role in automating organization and complex problem-solving remains an area for future investigation (Sapkota et al., 2026).

Ultimately, we advocate for a philosophy that avoids the technological race. Rather than worrying about the rapid advancements of others, we focus on using AI as a highly efficient, multitalented, but fallible assistant tailored to our specific educational goals. While LLMs with chat-based interfaces have only been publicly available for a relatively short period of time, the progress has been extraordinary; what the world of technology or education will look like in just a few more years is currently unimaginable. By keeping the student abreast of these latest technologies, we ensure they are prepared for the future direction of society, regardless of where it leads.

5. Conclusion

The integration of Artificial Intelligence into the elementary curriculum marks a fundamental shift

from the textbook-and-rote model to a synthesis-and-verification framework. Our case studies demonstrate that AI serves as a powerful pedagogical force multiplier, enabling a single educator to curate sophisticated, interdisciplinary lessons at the "speed of thought." By acting as an interpretive bridge between traditional subject barriers, AI makes advanced concepts - from 3D map projections and algorithmic time complexity to the amygdala's role in emotion - accessible to Grade 1 and 2 students. Our advanced homeschooling setup combining ergonomic safety and distraction-free learning with digitization provides a replicable model for modern education. By preserving every lesson, homework, and project in a digitized, AI-integrated cloud, we ensure that a student's intellectual development is permanently documented and searchable. While technical limitations persist in AI-enabled support, they serve as vital teaching moments that reinforce the necessity of human oversight. The significance of this study is amplified by the unique interdisciplinary position of its authors. This work moves beyond traditional academic boundaries by uniting a deep background in advanced AI and scientific research with the daily realities of early childhood education. This combined expertise allows the study to offer a rigorously designed, technologically sophisticated, and practically tested model for the future of learning, providing a rare and comprehensive example of 'researcher as practitioner' in a frontier domain of educational design.

Crucially, this framework redefines literacy for the digital age, transcending age-graded boundaries. Success in an AI-integrated environment is not measured by the ability to generate information, but by the capacity to verify it (for example, hallucinations and errors in code or logic). Whether it is a university student defending an AI-augmented dissertation or an adult learner in a professional upskilling program, the requirement for technological agility and critical verification remains constant. By engaging with AI as a fallible collaborative partner from the onset of education, we enable a generation of learners to develop critical thinking skills essential for navigating a technological landscape defined by exponential change, where they are not just passive consumers of machine intelligence but its primary architects and critical auditors.

AI use declaration

During the preparation of this work, the author(s) used Gemini for writing assistance and data analysis. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication. The author(s) have verified all AI-generated content for accuracy, confirmed that AI is not listed as an author, reviewed language suggestions, validated all data analysis, checked all code outputs, and reviewed the work for bias and ethical considerations.

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