Construction and Exploration of an Intelligent Analog Electronics Course Based on Generative AI

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Abstract: Facing to some teaching pain points in the course of " Analog Electronic Technology ", such as the knowledge is fragmented, the learning situation feedback is delayed and the self-directed learning efficiency is low, in this article, at the aim of the generative AI technology is integrated with Chaoxing Learning Platform, a visualized curriculum knowledge graph containing the ideological and political education element is constructed, and a full process intelligent learning status monitoring system is set up, this study constructs the hierarchical and personal hybrid smart classroom paradigm. The teaching practice proves that this model can help the students to build up the systematic knowledge system, realize the precise teaching and individualized instruction, and also to improve the teaching quality and learning effect.

Keywords: Analog Electronic Technology; Generative AI; Knowledge Graph; Intelligent Teaching

1. Introduction

The convergence of artificial intelligence (AI) and the practice of pedagogy has placed smart education in the list of strategic issues of contemporary higher education reform. In conformity with the Digital Education Initiative of the Ministry of Education, in the universities nowadays we are asked to use and exploit AI, big data analytics and the ecosystem of learning platforms in order to reconfigure the classroom not as a technological overlay but as epistemological and methodological renewal [1,2] of the teaching: in order to go beyond the persistent structure constraints of the conventional teaching, such as the homogenization of the curriculum, the temporal latency of the formative feedback and the too much trust on the experiential judgement of the instructor, going, probably, from the paradigm transmission of knowledge towards the cultivation of the competences, the adaptive scaffolding and the precision oriented support of the learner.

Analog Electronic Technology is a fundamental core course of all the discipline of electrical, electronic, and all the related engineering disciplines. Its content involves a number of interrelated fields: semiconductor device physics and modeling, analysis and design of single stage and multistage amplifier, feedback network synthesis, integrated operational amplifier (op-amp) circuit application, and regulated power supply system etc. It is characterized by the content density of concept, the strong connection between theory and practice, and the embedded parts of ideological and political education (IPE), such as engineering ethics, scientific integrity, values of the development of the nation through innovation [3,4].

However, traditional instructional delivery is still mainly chapter-sequential and lecture-dominant and produces same pace, presentation of concepts in a decontextualized way, and little cross-topic integration. Since the course is at high level of abstraction, has granular conceptual dependencies, and knowledge is in the form of cumulative, in most of the times the students do not have metacognitive strategies and structural thinking tool to build on their own coherent mental model or knowledge schema in the form of hierarchy, thus a fragmented understanding, weak knowledge transfer and less ability of doing authentic engineering problem solving [5,6].

In addition, the current assessment practices are still overwhelmingly summative and unidimensional, based on static yardsticks such as, for instance, the number of home works completed and on paper based periodic exams. These backward looking instruments do not foster any online, fine grained, real time insights on the way in which the learners are evolving their conceptual understanding, how the cognitive load is being distributed, or the specific trajectory of their misconceptions in the domain [7]. In this way, the timely, differential pedagogical interventions are systematically prevented; the learning gap is built up progressively, and it can end in premature abandonment of course knowledge - especially for the academically vulnerable. At the same time, the self-directed learning does not have any empirically grounded way of guiding the pathways, context aware resources curation, and embedded way of monitoring of the progress, prompting and reflective consolidation, and this is severely constraining the efficacy, sustainability and equity [8,9] of the self-directed learning.

In order to tackle these systemic pedagogical challenges, in this study we propose and put into practice an AI-enhanced hybrid intelligent teaching for Analog Electronic Technology [10,11] based on the Chaoxing Learning Platform and with the abilities of generative AI including intelligent tutor agent, auto-generated formative feedback, and multimodal learning analytics. It is based on the three theoretically well-matched pillars, i.e., (1) systematic knowledge construction by scaffolding, (2) continuous multidimensional learning state monitoring, and (3) agency-centered autonomous learning empowerment, and thus provides an evidence-informed and scalable model for AI-integrated curriculum innovation in basic engineering education. It provides both empirical support and conceptual renewal toward the strengthening of the mastery of discipline, the improvement of the learning persistence, and the formation of robust engineering identity.

2. A Critical Analysis of Pedagogical Challenges in Traditional Analog Electronics Classroom Instruction

The instruction of analog electronic technology is characterized by the conceptual width, the structural height and the high degree of interdependence of the topics that concern the core of the course, with the course content organized in a rigorous progressive and hierarchical logical order. The inadequate internalization of the basis semiconductor devices, in particular of diodes and of the bipolars junction field-effect transistors, systematically limits the students' capacity to understand and use notions of more advanced topics, like the principles of the design of the amplifiers, the topologies of the feedback network, and the configurations and the applications of the integrated operational amplifier (op-amp). The common pedagogical practice follows for the most part a linear, chapter sequential delivery of the course, in which the teachers provide to the learners the transmission of the declarative knowledge of the isolated concepts, without a explicit scaffolding of the relations of the concepts or of their integration in a unified theoretical scheme: the learners therefore having a passive reception of the fragmented information, so that they can not autonomously construct the conceptual hierarchies and the link of the topics that are the preconditions of the construction of a good, transferable knowledge schema. This epistemological fragmentation is often shown in the form of a cognitive dissonance, of a conceptual misattribution and of a less efficacy in the solving of the problems when faced to integrative design tasks or to the solving of real engineering problems.

Assessment in analog electronics education is still mostly retrospective and summative. The current practice of assessment is based on the metrics in the endpoint, namely the homework, unit tests, and final examination, and the mechanisms of formative assessment and real time learning analytics are not sufficiently elaborated. In other words, the fine grained process data, such as the how ready was the student with concepts before the class, how was the student engaging with the material in class, and what was the student doing in order to consolidate what he/she has learned after the class, is not yet mined. This would not allow the instructor to be able to dynamically identify an emergent learning hurdle, that is a persistent misconception, a fragile mental model, or a domain specific error pattern, in order to have an agile, data driven intervention. Remediation is not a proactive but a reactive, it is done usually only when the deficiencies are piled up. This delay is detrimental for the agility of the instruction, for the fidelity of the feedback loop and for the efficacy of the learning.

Contemporary evaluation frameworks over-index on terminal written examination performance, and fail to systematically appraise students' metacognitive development, knowledge-construction processes and self-regulated learning competencies. Such unidimensional metrics do not enable the educator to triangulate the learning evidence from several sources (of the behavioral, cognitive and affective dimension) for the purpose of a diagnostic pedagogical analysis. Hence, they do not allow for the data driven refinement of the sequencing, pacing and the instructional strategies of the curricula and, in the first place, they basically block the possibility of having a responsive, iterative of an instructional cycle based on the of the teaching enactment-learning analytics - pedagogical adaptation.

Independent study is an important, but systematically under-supported, part of the education of analog electronic technology. Under the current instructional models, the learner has no empirically informed, adaptive, guidance for designing the learning pathway, for curating the resources appropriate for the context and for aligning the practice with the diagnostics. Students with some first steps below may have the learning behavior of being non discriminative in their problem selection, or of some rehearsing of the already mastered constructs, mostly because they do not have the precise, actional feedback of where is their conceptual stand. On the other hand, the academically advanced has the little opportunity for some scaffold of extension, and therefore has less engagement, less to do. Finally, the not having of something embedded with accountability, like the progress being tracked, the prompting being adapted, and some reflective stopping to check the learning, does not support the behavior to be consistent and to keep the action of independent study for long, which largely diminishes the learning efficiency and the retention.

3. Construction Scheme of Smart Teaching System for Analog Electronic Technology Course Based on Generative Artificial Intelligence

This study tackles the long-standing pedagogical issues in the instruction of the ‘Analog Electronic Technology’ (a typical engineering basic course with high conceptual density, cumulative knowledge dependence, and strong theory-practice fusion) by the combination of the Chaoxing Learning Platform with the generative artificial intelligence (GenAI) technology in this paper. We present a smart teaching scheme which is theoretically reasonable and empirically implementable, with three pillars involved: (1) the GenAI-based structured knowledge organization; (2) the GenAI-based real-time multidimensional learning status monitoring; (3) the data-informed personal self-directed learning empowerment. The instruction cycle is not divided as the pre-class/in-class/post-class phases, but as a continuous feedback learning loop in this smart teaching scheme. It takes the course instruction forward to the systematic knowledge coherence, the pedagogy in pointed and precision, and the development of the learners in the course.

3.1 Reconstruction of the Course Cognitive Architecture via AI-Enhanced Knowledge Graphs

Analog Electronic Technology has a tightly coupled, hierarchical and logically progressive knowledge topology. For example, the mastery of advanced circuit theories is based on the good nature of basic and the characteristic of device. The negative feedback circuit analysis is based on the fundamental of amplifier, and the fundamental of amplifier is based on the semiconductor device physics. But the traditional textbooks in linearly organized way, do not reflect the intrinsic logical dependencies and networked relation of knowledge nodes, so these knowledge nodes are studying by students in a very fragmented way. The students tend to master the discrete knowledge of chapter rather than the systematic discipline framework. Thus, the students can not develop the ability of their comprehensive thinking and autonomous learning.

In order to solve the problems of the fragmented and unsystematic learning in the course of Analog Electronic Technology, in this study, the knowledge architecture of the curriculum is reconstructed by generative AI and domain ontology engineering. Based on the requirement of the syllabus and the goal of talent cultivation, the five main modules, such as semiconductor fundamentals, basic amplifier circuits, integrated operational amplifiers, feedback amplifier circuits, and DC regulated power supplies, are systemically organized. In this way, such an approach breaks the constraints of the teaching in the linear chapters, and the scattered knowledge is integrated into a system.

The knowledge graph is built in the standard three stage framework as follows. 1) Core concepts, theorems, circuit topologies and analytical methods are divided into fine-grained knowledge pieces, and the cross-chapter prerequisite relationship, the logical sequence rules and the relationship of engineering application of these knowledge pieces are defined and encoded clearly. 2) We set up the whole multidimension metadata tagging to fuse the key teaching points, the difficult content and the common mistakes of students. The multimodal teachings, such as the simulation demonstration, exercises and instructional videos, are exactly matched to the corresponding knowledge node for adaptive teaching.

Third, the optimized dynamic knowledge graph is embedded into the intelligent classroom of the Chaoxing Learning Platform. It can present the interconnected course knowledge in the way of visualized, hierarchical and traceable, and turns the static content in the textbook into the computable, adaptive knowledge infrastructure. The proposed system can optimize the learning path, decrease the knowledge fragmentation, and provide a good foundation for the personalized autonomous learning.

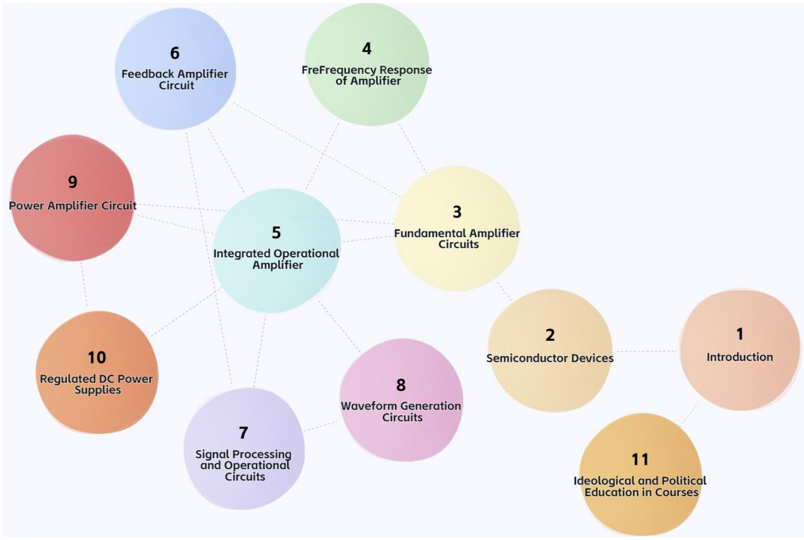

Figure 1. Knowledge Graph Navigation Map for the Analog Electronics Course

In addition, this study is also the first time that the ideological and political education (IPE) is integrated in the knowledge graph. The elements of IPE, such as the engineering ethics and the national scientific and technological self-reliance, are embedded in the important knowledge nodes, which realizes the combination of the teaching of professional knowledge and the cultivation of values. At present, the knowledge graph is the core intelligent navigation tool of the teachers' instructional design and the students' independent inquiry learning. The overall interface and structure of the knowledge graph are given in Figure 1.

Based on the knowledge graph, in this paper, the ideological and political dimension contained in the Analog Electronics course in the process of curriculum development is summarized according to the knowledge graph. At the same time, the "course ideological and political education" module is established in the course graph, and the special associative relationship, "ideological and political integration" is added, so as to intelligently integrate the knowledge point and the elements of ideological and political, so as to realize the information fusion, intelligent integration and visual presentation in the graph structure.

On the construction of knowledge graph for each curriculum module, we named three kinds of logical connection between the core concepts as the parent-child hierarchical relation, the prerequisite-successive sequential relation and the associative correlate relation. According to the discipline features of Analog Electronic Technology (AET), we supplemented extended engineering applications for each knowledge node. The constructed knowledge graph corresponding to basic amplifier circuits is shown in Figure 2.

Knowledge graphs make the architecture of a course visually available and explain the conceptual dependencies. Using the AI driven adaptive routing the system is able to build individual pathways: for students with gaps in the basics it will reinforce prerequisites and for more advanced ones it will show the engineering applications in the hard parts. This creates a self-regulated, non-fragmented way of learning to systematically master the analog electronics. In addition, the IPE attributes are intrinsically embedded in the graph so that the values will co-evolve with the technical levels.

This framework is implemented via the Chaoxing platform, which combines the hierarchies of the graph with the multimodal of data, the pre-class quiz, the assessment and the simulation errors, to able to sequence adaptively and scaffolded. Figure 3 shows the application of knowledge graphs in the learning maps, taking as an example the feedback amplifier circuit module, that represents the learning pathway, the learning status and all the other aspects related to the learning.

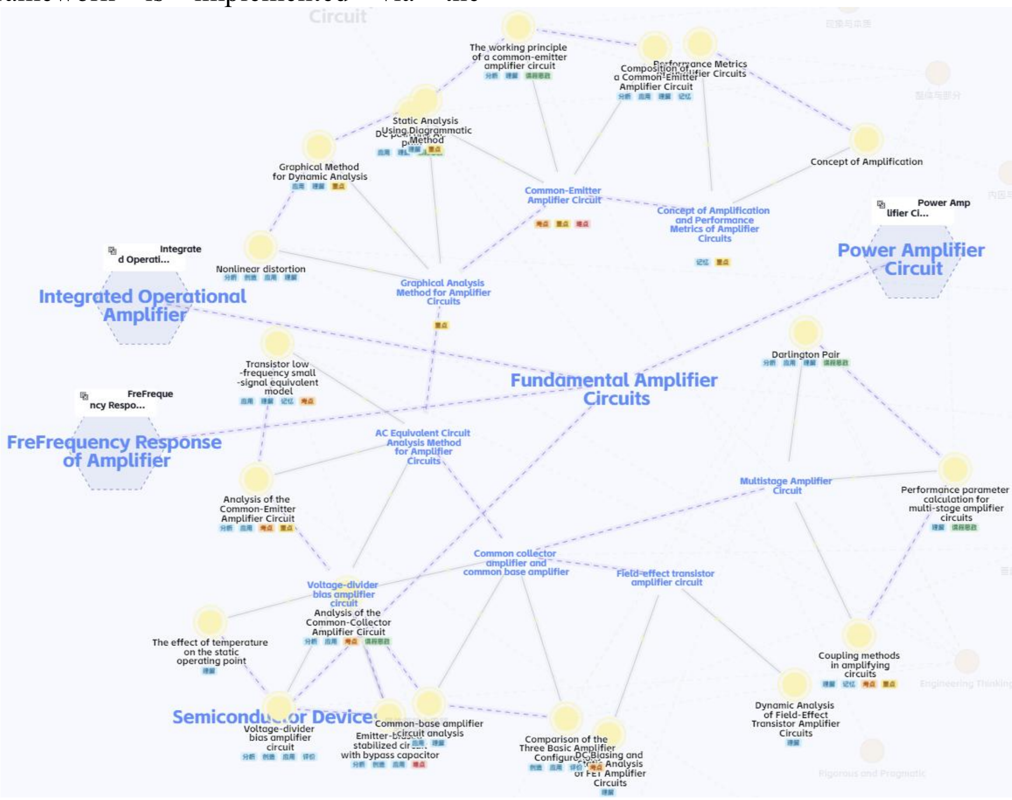

Figure 2. Knowledge Graph of Basic Amplifier Circuit Module

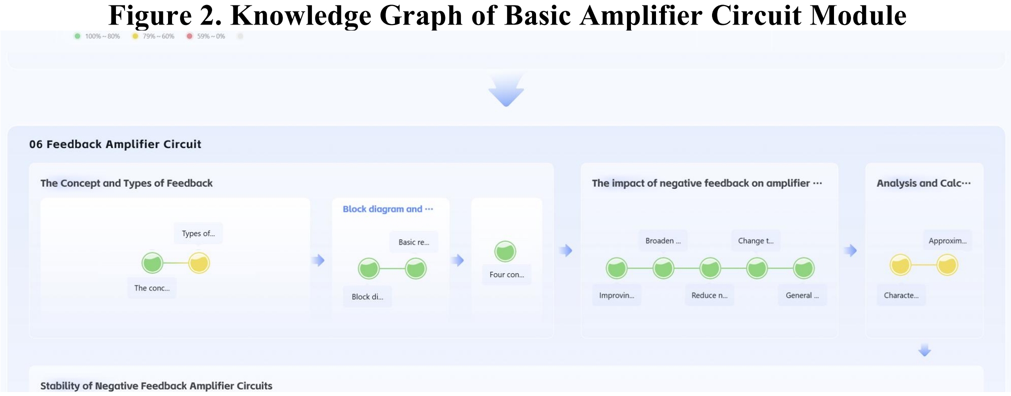

Figure 3. Learning Map of Feedback Amplifier Circuits

3.2 Generative AI-Driven Intelligent Learning Analytics and Precision Feedback

In this study, we address three fundamental problems of the teaching of analog electronics, i.e., the problem of delayed feedback, the problem of weak formative assessment, and the problem of data-poor interventions, which lead to the gaps of knowledge and the gaps of academic. We build a closed loop of the framework: data acquisition -diagnosis -risk prediction- precision intervention, using the generative AI module of the Chaoxing Learning Platform, from pre-class, in-class, to post-class, then let the teaching from the intuition to the data.

The data that the system gathers are the data of the process: when the class is completed, what is being done in the classroom, what are the homework / quiz results, what are the errors, what are the concepts mastered, that is, what is done (and not just what is the final grade).

This data is analyzed by AI in order to provide class dashboards and individual reports. In contrast to the manual review, it identifies the particular problems: e.g., recurring misconceptions (misapplication of the criteria for the feedback to be stable), weak knowledge of the important concepts and procedures errors, which allow for exact teaching interventions.

Figure 4. AI Learning Performance Statistics Interface

The system gives a real time alert when the student is far behind or repeating the same error, and it gives the practice that is in need (i.e. the practice that needs to be done quick in order to correct and not to leave a gap in the the student knowledge that grows if not corrected).

A teacher can use an intuitive dashboard to see the trend of the class, the groups of students and the common mistakes. Then the reviews are focused on the common weaknesses, he supports individually the learners that are struggling and he challenges the advanced students, instead of one size fits all, to an instruction that is responsive to the evidence. Figure 4 shows course learning statistics covering chapter task completion, homework completion and comprehensive average scores.

4. Implementation and Application of Pedagogical Practice

The 2024 Communication Engineering cohort in this study took two parts for a semester smart classroom reform. The reform was operated through the Chaoxing Learning Platform, with two parts in the mind: the Knowledge Graph and the AI-Powered Learning Analytics. The two tools supported the blended learning based on four parts for a full cycle of learning: pre-class to build the foundation, in-class to teach the course, post-class to consolidate and the full cycle to monitor.

In the phase of pre-class, the instructors used the generative AI to draw the hierarchical structure and the semantic relation of the concepts of analog electronics. As a result, a knowledge graph of the structure and a digital warehouse with micro-lectures, case and different forms of learning materials were built, and the basic condition for personalized inquiry and differentiated instruction was created. In the phase of classroom, the old one size for all approach was changed to the preview report which was generated by the AI and which can diagnose the learning status of the students. The teaching priority and the teaching pace could be adjusted in the dynamic manner. Also, the interactive feedback in the real time could let the instructor know how well the students learn the important topics, such as analysis of an amplifier circuit and identify the feedback. This change of lecturing from the experience to the intervention by the data, improved the efficiency of classroom much.

In the post-class phase, a closed-loop management of the learning, the assessment, the evaluation and the support were used. The AI system collected the data of the class activities, the assignments and the quizzes from the classroom and automatically found both the ones that are the personal knowledge gaps and the ones that are the common class wide misconceptions. The platform of the AI system of activated the early warning, in the form of intelligent reminder and the tasks to do to recompute the errors and reinforce the weak points. In the meantime, the instructors used the learning diagnostic reports to modify the content of the review and the way to tutor the class in order to avoid to cumulate the not yet solved knowledge gaps.

During the implementation, the system was constantly capturing the process-oriented learning data in order to follow the students run and to put in action the intelligence of the alerts. At the end of the course, the reform was checked using the anonymous questionnaires and the quantitative data generated by the platform. Thus, since we had an approach of the study by both the subjective and the objective dimension, we had the validity and the reliability of the results.

5. Teaching Effectiveness Survey and Analysis

In order to assess the practicability of smart classroom implementation, at the end of completing the target course, the students have an anonymous questionnaire survey. There are 45 valid responses in the survey. The questionnaire is centered on AI empowered teaching, it consists of 4 dimensions: 1) Intelligent resource development, 2) AI tool application, 3) Blended teaching model, and 4) Integration of ideological and political education with information technology.

From the survey, 93.33% of the students were satisfied with the diversified, tiered and multidimensional teaching resources in the smart classroom (Figure 5). Compared with the course resources of the traditional course of Analog Electronics, the multimodal resources (courseware, micro-lecture, exercise, simulation case) which is developed based on generative AI are more in line with the needs of learning, such as previewing before class, consolidating after class and getting over difficult points, to help the master of knowledge.

Students approve and are satisfied very high in AI-augmented instruction, e.g., for intelligent-platform embedded AI tutor, learning analytics and knowledge graphs. In AI-augmented instruction, 91.11% of the respondents responded Yes that generative AI features (smart Q&A, knowledge decomposition, interactive practice) greatly optimized his/her Analog Electronics learning.

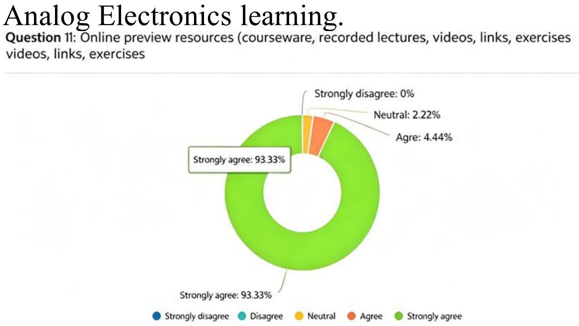

Figure 5. Survey Results on Satisfaction with AI Course Resources

The difficult topics such as the analysis of the amplifier dynamic and judgment of negative feedback are also targeted. The AI with knowledge graphs offers the personal learning route, the target resource, the modular knowledge decomposition, the all time tutoring and the theme exercises. It makes up for the drawback of lecture heavy and slow feedback in the teaching of the analog electronics, and with the customized intervention of one individual knowledge gap.

Generative AI plus course knowledge graphs can make students better to master the curriculum structure and knowledge correlation, solve the dilemma of understand but cannot apply, and lift the learning efficiency and the depth of understanding a lot. The details of survey are shown in Figures 6-7.

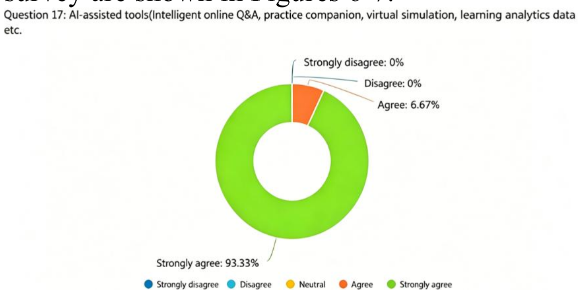

Figure 6. Survey Results on the Effectiveness of AI-Assisted Tool

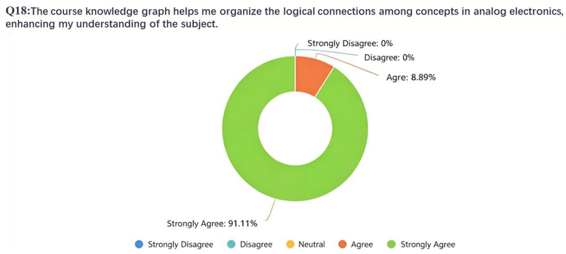

Figure 7. Survey Results on the Effectiveness of Course Knowledge Graph Usage

In the practical exploration of the smart teaching model, the survey data shown in Figure 8 shows that more than 90% of students think the online interaction has greatly improved their learning initiative. On the other hand, more than 90% of people think that the "online –offline" blended teaching mode is better than the traditional purely offline classroom in teaching pace and teaching efficiency. Also, the timely homework and the accurate feedback have helped the students to find the knowledge gap and deepen the internalization. These results show that the AI enabled closed-loop smart classroom model for Analog Electronics is consistency with the contemporary college students' learning habit and cognitive pace and can solve the always existing problems in the traditional classroom such as homogenized content delivery, delayed feedback and not enough personalization.

In summary, the generative AI enabled knowledge graph for analog electronics is beyond the teaching paradigm of parts, which helps the students to build up the whole knowledge framework and improve their abilities in understanding and all-around use. If combined with the AI-based exercise delivery, class interaction, full cycle learning analytics and intelligent diagnostic early warning, it will form a closed-loop teaching system with real feedback. It owns the characteristics of being in the style of students' autonomous learning, avoiding the knowledge gap and academic scatter, so it can comprehensively raise the pertinence of teaching, the efficiency of learning and the effectiveness of instruction.

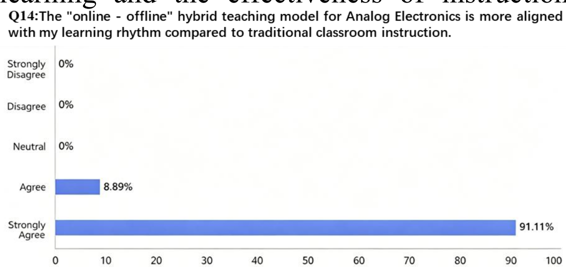

Figure 8. Evaluation of the Blended Model for Smart Teaching

6. Innovations and Limitations

This pedagogical reform based on generative AI constructs the knowledge graph for the course Analog Electronics, which systematically and visualizes the knowledge points to help the students to construct a complete holistic knowledge framework. It well solves the common long-standing problems of the fragmented and disconnected content in the traditional instruction, and provides a new paradigm for the systematic teaching of the foundation course of engineering. By using generative AI, the reform realizes the learning analytics that is multidimensional and real-time, which dynamically monitors the learning process and to generate the personalized learning profiles. It gives the foundation for evidence-based teaching for the teacher and evidence in learning for the student, while enables the dynamic optimization of the teaching strategy and the teaching intervention in different grades. The AI based personalized learning path planning and the intelligent reminder mechanism makes the students to shift from the passive reception of knowledge to the active learning planning, self-diagnosis of the learning deficit and the timely remediation. It not only improves the academic result, but also cultivates the core competencies of the student in autonomous learning and inquire. The course deeply combines the ideology and political element with the intelligent teaching ways, and embed the value guidance in the knowledge transmission and the competence cultivation, so it realizes the goal of the synergy of education of knowledge, ability and virtue.

The reform in the education of analog electronics driven by AI has got significant results, but there are still some points for better optimization: first, the knowledge graphs need finer granularity, simpler relationship, and more content on the engineering application and competition extending; second, both teacher and student have very low usage rate of smart platform and the AI tools, the guidance for the intelligent learning should be stronger; third, with the learning analytics based on AI, the learning path of personalized learning and the precise resource recommendation mechanism should be deepened.

7. Conclusion

Considering the three major problems that have long troubled the teaching of analog electronics courses in general, such as fragmentation of knowledge, delayed feedback on learning performance, and low effect of the students' self-directed learning, in this study, with the help of the Chaoxing Learning Platform and the technology of generative AI, the hybrid intelligent teaching model based on the three core modules of the knowledge graph guidance, adaptive resource provision, and learning-analytics-based diagnosis is constructed.

The knowledge graph can achieve systematic reconstruction and logical explicitation of the course knowledge, and facilitate students' transition from the memorization of discrete knowledge to the structured the cognition of knowledge, which greatly enhances the depth of knowledge understanding, the stability of mastery, and the capacity of knowledge transfer and application. Multimodal AI-powered teaching resources can strengthen the personalized content delivery, break through the spatiotemporal limitations, and create immersive and highly initiative learning environment, which can stimulate students' learning initiative and improve their academic performance to some extent. Furthermore, the dynamic learner profiling and intelligent learning pathway planning mechanism based on multidimensional real-time learning analytics can also provide the data support of quantifiable and traceable data support for the instructors to implement the targeted instructional intervention and tiered guidance.

From the results of teaching practice and the questionnaire survey, we can see that this model really does make up for the structural gaps among the knowledge points and improve overall teaching effectiveness. This model has the practical reference value and can be scaled for the digital-intelligent transformation and innovative smart teaching pattern of basic science and engineering courses in higher education institutions.

Acknowledgments

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