

Original Paper

Building a Smart Curriculum for Core Engineering Courses through Teacher-Student-AI Interaction: The Case of Mechanics of Materials

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Abstract

China's national push for educational digitalization has made a lot of application-oriented universities rethink how they teach core engineering courses. They are trying to make these courses smarter, and that has become a big part of how they reform talent training now. Mechanics of Materials is a required course for mechanical engineering students, but teaching it well has always been hard. The theories are abstract, and they often feel cut off from real engineering work. Students come in with very different levels of preparation, and teachers just cannot give each student enough personal help in large classes. Our work is based on the provincial first-class undergraduate course at the University of Science and Technology Liaoning. We built a smart curriculum system that puts Teacher-Student-AI Interaction at the center, uses a knowledge graph as its backbone, connects everything through a course-specific AI agent, and runs on multi-dimensional evaluation. What we saw in actual teaching shows that this system helps fix old problems that traditional teaching has had for a long time. Students end up with better knowledge and stronger engineering practice skills. We think this gives other application-oriented universities a model they can use for their own foundation courses.

Keywords

Mechanics of materials, Wisdom course, AI empowerment teaching, ideological and political theories teaching in all course

1. Introduction

China's National Educational Digitalization Strategy has pushed digital technologies deep into higher

education. AI and big data, especially, are changing how teaching gets done. A question all universities now face is this: how do you use these tools to actually make courses better? More and more, the answer lies in building smart curricula. A smart curriculum is not just a bunch of digital stuff thrown together. It is a new way to think about teaching and learning, with the goal of giving students stronger knowledge and better practical skills (Song, 2024; Zheng & Ma, 2025). This shift matters even more for core engineering foundation courses, the kind that sit between general education and specialized training. These courses are where students really start to think like engineers. If we get the transformation right here, it changes everything that comes after.

Mechanics of Materials is a required course for programs like Mechanical Design, Manufacturing and Automation, and Intelligent Manufacturing Engineering. Its main job is to teach students how to check if engineering parts are strong enough, stiff enough, and stable enough. That is the foundation for designing things that are both safe and economical. The students taking this course are a mixed group. Some are regular undergraduates, and some come from top-up programs. Their math and mechanics backgrounds are all over the place, and that creates real problems for teaching. Traditional teaching runs into four big difficulties. The first one is that the course material is abstract, and the formulas are complicated. Students have a hard time connecting the mechanics models to the formulas and then to real engineering work. They just do not get a good gut feeling for the core ideas. The second problem is that the same teaching method gets used for everyone, but students need different things. Some cannot keep up, and others are bored because they are not being pushed enough. That leads to a big split in learning outcomes. The third problem is about ideological and political education. The way it gets added in is often stiff and shallow, like just slapping a label on something. It does not really mix engineering ethics and craftsmanship into the professional knowledge in a deep way. The fourth issue is class size. When classes are large, there is just no way for teachers to give one-on-one help. Student questions after class get answered late, and that hurts both teaching efficiency and how much students actually learn. Recent work on material mechanics teaching under the national “101 Plan” has also pointed out that teacher and student roles need to change in an AI-driven world (Yin, 2025).

So we looked at all these problems and decided to draw on more than ten years of teaching reform in our university’s Mechanics of Materials course. The course is already recognized as a provincial online-offline blended first-class undergraduate course and a provincial high-quality CIPE course. We also brought in a virtual simulation experiment we built ourselves, called “Normal Stress Analysis of a Single-Girder Overhead Crane,” which is hosted on the National Virtual Simulation Experiment Teaching Platform. We put all of this together to build a smart curriculum system based on Teacher-Student-AI Triadic Interaction. Here is how the three parts work. The “Teacher” leads instruction, focusing on explaining the hardest points, giving value guidance, and making better teaching decisions. The “Student” is the main actor in learning and uses personalized resources to learn through their own exploration. The “AI” is the tool that makes things possible. It uses AI agents, knowledge graphs, and big data to give smart help to both teachers and students through the whole

teaching process. This paper lays out the whole framework, the practical steps we took, and what results we got. Our hope is to give other people working on similar engineering foundation courses something useful they can learn from.

2. Overall Construction Framework of the Teacher-Student-AI Triadic Interaction Smart Curriculum

The whole smart curriculum was built around the OBE idea of being outcome-oriented, student-centered, and always improving. Our main goals were to help teachers teach more precisely, let students learn in their own way, and use AI to make everything smarter. We set up a complete system we call “1 Core, 4 Pillars, 5 Supports” (see Figure 1). Other people have shown that this kind of OBE-driven approach works well for restructuring curriculum design in mechanical engineering education (Li et al., 2025).

The “1 Core” is the Teacher-Student-AI Triadic Interaction, which goes through everything we do. The “4 Pillars” are what we want to achieve. The first is knowledge mastery, meaning students remember more of the core stuff and do better on final tests. The second is competence development, meaning students get better at engineering mechanics modeling and solving complex engineering problems. The third is quality cultivation, meaning students build up craftsmanship, engineering ethics, and a sense of wanting to serve the country through science and technology. The fourth is model innovation, meaning we end up with a smart teaching model that other people can copy and scale up. The “5 Supports” are the five building blocks we used: new-format teaching resources, a course-specific AI agent, AI-assisted teaching, organized knowledge units, and new-format textbooks. All these pieces connect to each other and work together to form a complete closed loop for building the smart curriculum.

2.1 Structured New-Format Teaching Resource Development Centered on a Knowledge Graph

Teaching resources are the base of any smart curriculum. Our course brings together quality, competence, and knowledge into one system. We built four interconnected graphs: one for knowledge, one for competence, one for problems, and one for ideological-political education. Someone else has already shown how a four-layer knowledge graph can be built and used to help students learn material mechanics better (Zhang et al., 2025). We went through more than 150 core knowledge points, took each one apart, and figured out what comes before it, what comes after it, what abilities it points to, where it gets used in real engineering, and what the teaching requirements are. Then we connected all the dots. We linked knowledge points to competence requirements like engineering modeling and design, to typical engineering problems like strength and stability, and to ideological-political elements like craftsmanship and engineering ethics. The result is a standard, three-dimensional knowledge network that can be updated as needed.

On top of that, we built a standard engineering case library for the main chapters. Each case covers the engineering background, the mechanics model, the calculation process, safety specifications, and CIPE integration points. We also went through our existing micro-lecture videos, kept the good ones, and

made at least eight new AI-interactive ones for the hardest topics. Each of these comes with an in-class self-test, extra materials, and an AI Q&A button. The “Normal Stress Analysis of a Single-Girder Overhead Crane” virtual simulation experiment was already online on the national platform. We upgraded it with AI, adding real-time prompts, warnings when parameters go over the limit, help when students make mistakes, and automatic delivery of engineering ethics content. All of this together gave us a four-in-one teaching resource system: graphs, cases, micro-lectures, and virtual simulation experiments. That is the resource base for everything else we do with AI-assisted teaching.

2.2 Technical Support System Anchored by a Course-Specific AI Agent

We used the smart teaching platform our university already has and connected it to large language models like DeepSeek and Huiya. On top of that, we built an AI agent just for Mechanics of Materials. The agent does three main things: it answers questions any time of day, it analyzes how students are learning, and it recommends resources that fit each student. These functions work across the whole teaching process, before, during, and after class. Other researchers have found that AI-enabled smart courses can really change how teaching works at the college level (Lv, 2025).

To make sure the agent gives accurate and professional answers, we fed it a lot of material. We put in the syllabus, the textbooks, the courseware, micro-lecture videos, test banks, CIPE case studies, virtual simulation lab manuals, and a big collection of questions students have asked over the years. We sliced all of this into knowledge pieces, gave each piece a label, and organized everything into a large private knowledge base for the course. Everything in the knowledge base is linked to specific knowledge points and competence points. We also set up three layers of quality checks. The first is real-time teacher intervention, which lets teachers adjust how the agent answers questions and what resources it recommends. The second is a manual backup for hard questions that the agent cannot handle. Those get sent straight to the course instructor. The third is a weekly review done by team members working in rotation. They check the AI’s answers and the knowledge base for mistakes. All of this keeps the agent working well over time.

2.3 Full-Process AI-Assisted Smart Teaching Model

We put the Teacher-Student-AI Triadic Interaction into every stage of teaching, before class, during class, and after class. The AI agent sits at the center and connects everything. This setup frees teachers from doing the same basic stuff over and over, so they can spend more time on tough topics and guiding students’ values. That is how we make teaching fit what students actually need. This way of teaching fits with what other people have been saying, that engineering courses should be more application-oriented and use project-based methods and different kinds of evaluation (Research on Teaching Reform and Practice of Mechanics of Materials Course Based on Engineering Application, 2025).

Before class, the AI agent looks at each student’s past learning data and their knowledge profile. Then it sends different stuff to different students. Students who need to catch up get short videos on basic concepts and simple self-tests. Students who are ready for more get case analyses and harder exercises.

The agent grades all the self-tests by itself, puts the data together, and makes a report that shows where the whole class is weak and where individual students are struggling. That lets the teacher adjust the lesson plan before class even starts.

During class, an AI teaching assistant handles the routine stuff. It answers simple questions, helps guide group discussions, and collects quiz results automatically. That gives the teacher real-time feedback on whether students are getting it. In the virtual simulation experiments, the AI guides students through the whole process, reminds them about key parameters, and points out when they do something wrong. The teacher watches all of this on a big screen, seeing students' learning data, what they are doing, and what questions they are asking the AI. That lets the teacher focus on the hard parts and work in the CIPE value guidance. It is a team effort between the teacher and the AI assistant. One thing to point out is that the AI's recording of lecture points and matching them to knowledge graph nodes depends on the platform's speech recognition and language processing abilities. That part is still experimental and can be adjusted depending on what the platform can actually do.

After class, the AI agent uses how students did in class to create personalized homework and review plans. Different students get different assignments, and the system recommends the right extra materials for each one. Every month, the system also puts together a learning report that looks at how students are doing over time and what issues the class as a whole is facing. Teachers use these reports to change their teaching strategies and give focused help to students who need it. All of this makes a complete loop of learning, diagnosis, feedback, and consolidation.

2.4 Virtual-Real Integrated CIPE Education System

We already had a provincial high-quality CIPE course to build on. We made two CIPE syllabi that spell out five main goals: patriotism, craftsmanship, scientific innovation, engineering ethics, and teamwork. We found thirteen places in the core chapters where CIPE fits naturally. Then we made a standard template that goes from knowledge point to ideological-political element to engineering case to reflection question. This template fixes the old problem of CIPE feeling separate from the actual course content.

We used the virtual simulation experiments and the AI agent to create a mixed virtual and real environment for CIPE. Engineering ethics and craftsmanship are now woven through every step of the lab work. The system warns students when they set parameters too high, it sends them case studies of real engineering accidents, and it explains safety codes and standards. Students learn, by actually doing, that behind every number is a real piece of equipment, and behind every piece of equipment is a real responsibility. We also put hidden reflection questions into homework assignments and lab reports. The AI agent looks at the words students use in their reflections and picks out ethical keywords. That gives us a way to measure how well the CIPE work is going and shifts things from just telling students what to think toward a more natural kind of influence.

2.5 Smart Digital Textbook Development

We followed the principles of intelligence, interactivity, and integration to design the framework for a

smart digital textbook. We laid out where each knowledge point goes in each chapter, where to put media resources, where to place AI interaction buttons, and how to link to the virtual simulation experiments. We finished one sample chapter from the core syllabus. In that sample, we put a 3D model demonstration, interactive example problems, a direct link to the course-specific AI agent, and a link straight to the virtual simulation experiment. That gives students an integrated experience where they can learn, practice, ask questions, and do experiments all in one place. This pushes the textbook from being a static thing to being a smart teaching tool that teachers can organize, students can explore, and AI can power up. It is a one-stop vehicle for students' own learning.

3. Teaching Practice Case Study

For the case study, we used Chapter 5, "Bending Stress and Deformation," from Mechanics of Materials. We picked two cases to work with. One was a real engineering job, checking the strength of a single-girder overhead crane's main girder. The other was a basic exercise, checking the strength of a T-section beam. We did the Teacher-Student-AI Triadic Interaction smart teaching over two class periods, 90 minutes total. Here is how it went.

3.1 Pre-Class: AI-Driven Precision Preview and Learning Diagnosis

The AI agent used the course knowledge graph and the students' past learning data to push different preview tasks to different students. Students at the basic level got short videos on bending stress formulas and section moment of inertia calculations, plus some simple self-test questions to nail down the core ideas. Students at the advanced level got engineering case studies about force analysis on crane main girders and articles about bridge collapse investigations to build up their engineering thinking. We also sent out a short ideological-political video called Bending Stress: From Zhaozhou Bridge to the Hong Kong-Zhuhai-Macao Bridge, so students started thinking about values before class even began. After students finished the preview tasks and self-tests, the AI agent graded everything and made a heatmap of how the class was doing. It clearly showed where the whole class was weak. Two things stood out: students had a 65% error rate on section moment of inertia calculations, and they were getting mixed up about how to combine different loads. So the teacher changed the classroom plan. He cut down the time spent on going through formula derivations and added more time for simple tricks to handle moment of inertia calculations and the real engineering rules for combining loads. That is how we did precision lesson prep.

3.2 In-Class: Triadic Interactive Synergy to Overcome Key-Difficult Teaching Points

We started the class by talking about the Quebec Bridge Collapse. Then we compared it to the safety design of the Hong Kong-Zhuhai-Macao Bridge. That got students thinking about the connection between parameters, equipment, and responsibility, which is the main thread of our CIPE work. It woke up their awareness of safety and accountability. For the teaching method, we used something we call "Student Lecturing and Peer Review plus Teacher Lecturing and Expert Review." One group of students explained how they solved the T-section beam strength check, and another group explained the

crane main girder strength check. The other groups gave comments and added things they noticed. While all this was going on, the AI agent was keeping track of the main points students made in their presentations. It tried to match those points to nodes on the knowledge graph and gave a heads-up when someone said something clearly wrong. That function depends on the platform's speech recognition and can be used flexibly in practice. The agent also made a classroom interaction heatmap. The teacher could pull up ready-made lesson plans for the knowledge points that were getting the most attention and do a quick five-minute lecture on the stuff students were struggling with together. He used a case about a crane main girder fracture to bring in engineering ethics and drive home the importance of craftsmanship and responsibility. Meanwhile, the AI assistant was handling basic questions from students in real time. That let the teacher focus on the really hard parts and on getting students to think more creatively. At the end of class, the AI assistant sent out three quiz questions and instantly showed how many students got them right. For any question where more than 40% of students were wrong, the teacher explained it right then and there so students got it before leaving.

3.3 Post-Class: Practice and Consolidation to Form a Teaching Closed Loop

After class, students got into small groups and talked about how to pick the right safety factor in engineering design. The AI agent sent them safety specifications from the mechanical and civil engineering fields, which helped them get a better feel for real design codes. Students then went to the National Virtual Simulation Experiment Teaching Platform through a link on the Chaoxing Platform and did the "Strength Verification of a Single-Girder Overhead Crane Main Girder" experiment on their own. They could do it anywhere and anytime. When they got stuck, they could go back to Chaoxing and ask the AI assistant for help right away. Other engineering fields have used similar computer-based virtual reality tools and found that they make teaching more effective (Liu et al., 2024).

The lab report template had a hidden reflection question built in, following the same "parameter to equipment to responsibility" thread. The AI agent helped look at the words students used in their reflections to find ethical keywords. That gave us a way to measure CIPE results. Also, using all the data from the preview, the classroom, and the experiment, the system made personalized review paths for each student. Students who were behind got basic exercises and short videos. Students who were ahead got a harder task, figuring out how to optimize a main girder design while considering fatigue strength. That is how we made sure every student got something that fit their level.

4. Construction Effectiveness and Dissemination Value

4.1 Course Construction Effectiveness

We tried this smart curriculum system in two classes of Mechanical Design, Manufacturing and Automation, and Intelligent Manufacturing Engineering Technology at our university, with 86 students in total. We compared the data from before and after, and the results were pretty clear.

First, students learned the material better. The average score on the core knowledge tests for Chapter 5 went up by more than 12 percentage points compared to earlier classes at the same stage. On the

knowledge graph, the red nodes, which show weak spots, dropped by 60%. Students got much better at understanding and using core ideas like bending normal stress and strength checking. The failure rate on the final exam dropped by 9 percentage points, and the class average went up by 6%.

Second, students got better at hands-on engineering work. The rate of setting the safety factor correctly in the virtual simulation experiment went from 45% to 85%. More than 90% of students could finish the main girder strength check the right way, following real engineering standards. That shows they were starting to think like engineers and could do basic mechanics modeling. Students also wanted to learn more on their own. The pre-class preview completion rate went from 72% to 93%.

Third, the CIPE work actually paid off. In students' reflection reports, words like "responsibility," "safety," and "ethics" showed up 100% of the time. More than 90% of students showed a good grasp of engineering ethics. They really got the idea that safety comes first and responsibility is everything in engineering design. The course evaluation scores on things like how inspiring the course was and how relevant it was to practice went up by 0.6 points on a 5-point scale, and more than 90% of students gave satisfactory ratings.

Fourth, teaching became a lot more efficient. The AI agent took over more than 80% of the routine stuff, answering basic questions, grading assignments, and putting together data. That saved teachers about 30% of their prep time. They could spend that time on the hard parts of teaching, designing CIPE activities, and helping individual students. The teaching team has published five teaching reform papers, landed two Ministry of Education industry-university cooperation projects, and got one provincial undergraduate teaching reform research project. The team's ability to do teaching research keeps getting better.

4.2 Dissemination and Application Value

The whole smart curriculum model is lightweight, cheap, and easy to copy. You do not need any complicated homegrown technology or a lot of money. It can run on the smart teaching platforms that most universities already have. That makes it very practical to spread around.

First, the CIPE integration template can be moved to other courses. The standard template we built, going from knowledge point to ideological-political element to engineering case to reflection question, does not need much changing to work in other fields like mechanical, civil, or aerospace engineering. That makes it easy to bring CIPE into engineering courses in a more natural way.

Second, the virtual simulation experiment model can be reused. The experiment resources are already on the national platform, and we are just using a link plus AI Q&A setup. No need to rebuild anything or spend extra money. Other departments and related courses can share the same virtual simulation resources. That makes the most of good experimental materials.

Third, the knowledge graph methodology can be copied. We have written up the whole process and the rules for linking knowledge points into standard documents. Other engineering foundation courses can use these documents as a starting point, which cuts down the time and cost of building their own smart courses.

Fourth, the teaching model can be spread around easily. The “Student Lecturing and Peer Review plus AI Assistance” Teacher-Student-AI Triadic Interaction model works on the platforms that are common in universities. No need to build anything new. It is cheap to spread and easy to put into practice. It fits a lot of different engineering foundation courses and gives application-oriented universities a real example they can follow for their own digital reforms.

5. Discussion

In the bigger picture of higher education going digital, making engineering foundation courses smarter is not just about throwing technology on top of old content. What really matters is putting students at the center and using technology to rebuild the whole teaching process so the old problems actually get solved. In this study, we used Mechanics of Materials as our example and built a Teacher-Student-AI Triadic Interaction smart curriculum system. By really digging into knowledge graphs, a course-specific AI agent, and virtual simulation experiments, we got to a place where teachers teach more precisely, students learn in their own way, and AI gives smart help through the whole process. The three-stage smart teaching model and the standard CIPE integration method we came up with can give other courses a theoretical framework to work from. The practical stuff, the knowledge graph building process, the AI agent setup, and the virtual simulation experiment model, are all lightweight, cheap, and easy to copy, so they fit what application-oriented universities need. Going forward, our team will keep working on making the AI agent’s functions better and updating the knowledge graph more dynamically. We will try the approach in more courses, share resources and experiences with other universities in the region, and keep polishing what we have built. The goal is to give people a better and better practical reference for making engineering foundation courses smarter, and to help application-oriented universities keep getting better at training engineering talent.

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