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Original Paper

Reform and Practice of Modern Cryptography Courses in Integrated Undergraduate–Graduate Cybersecurity Education: Science–Education Integration and AI as Dual Drivers

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Abstract

In order to tackle the problems that exist in integrated undergraduate–graduate cybersecurity education at provincial universities with significant differences in the level of student preparedness, lack of coherence between undergraduate and graduate programs, inability to transform the results of faculty research into instructional resources, and disjointed use of artificial intelligence, the given study uses the Modern Cryptography course which is provided to the undergraduate students, the academic master's students and the professional master's students in Cybersecurity at Heilongjiang University as a case study. Design-based action research methodology was employed in order to form a three-level curriculum chain of undergraduate foundations, undergraduate–graduate articulation, and advanced graduate-level research training. Moreover, a four-step mechanism for transforming research outputs into teaching resources was devised, consisting of selecting the research outcome, pedagogical adaptation, implementation in the classroom, and iterative feedback. AI-based learning diagnostics, literature assistance, and learning behavior recording were incorporated in the entire process of instruction. Five dimensions of process-oriented assessment were developed, namely: theoretical knowledge, practical skill, research-focused reading and participation in tasks, innovation capacity, and learning behavior. The initial pilot implementation involved using process documentation, laboratory reports, observation in the classroom and formative feedback as the main sources of evidence to determine the viability of the reform plan, the viability of collecting evidence and the completeness of the assessment chain. This paper has important practical implications to promote integrated undergraduate-graduate cryptography education and enhance the research-education integration reform in provincial universities.

Keywords

Modern Cryptography, Integrated Undergraduate–Graduate Education, Integration of Science and

Education, AI Empowerment, Action Research, Process-oriented Evaluation

1. Introduction

Due to the growth of digital infrastructures into industrial Internet, cross-border data flows, and intelligent manufacturing, there is more demand among cybersecurity professionals to be interdisciplinary, with such competencies as mathematics, algorithm implementation, and research and innovation abilities, and the awareness of regulatory compliance. The Modern Cryptography course is one of the key elements of the curriculum that bridges mathematical theory and algorithm design, security protocols, code implementation, and engineering practice and has played a central role in the education of the undergraduate students and the training of the graduate researchers.

The education system of cybersecurity at Heilongjiang University integrates the undergraduate program with academic as well as professional ones of master's program. Nonetheless, it is important to note that graduate students come not only from cybersecurity but also from other science and engineering disciplines, which leads to significant differences between them in terms of mathematical and programming backgrounds. Current courses are mainly taught as a unified program to graduate cohorts, where there is inadequate continuity of the task chain between the undergraduate foundations, graduate-level professional preparation, and research work; the specific goals of academic master's programs, which are based on theoretical analysis, and professional master's programs, which are based on engineering implementation, have not been adequately reflected in course requirements and evaluation criteria. However, the symbolic system, experiment, and security assumptions that are found in faculty research results are not easily transferred into the classroom instruction; a mere use of generative artificial intelligence as a question-responding device cannot be effectively utilized to promote differentiated instruction, practical feedback, and assessment by process as well.

In order to resolve the stated problems, the present paper explores the following issues: (1) what would be the solution to create a three-tier learning sequence that is able to accommodate differences in students' prior knowledge and ensure a steady advancement of undergraduate background to graduate-level professional education and research training; (2) what methods are available to convert faculty research findings into reproducible and assessable teaching tasks; (3) how artificial intelligence can be implemented into learning diagnosis, experimental practice, research-oriented reading, and process-oriented assessment without losing clear academic accountability.

2. Research Design

2.1 Research Participants and Action Research Cycle

The participants were undergraduate students whose field was Cybersecurity, master's students who were studying Cybersecurity academically, and professional master's students in Network and Information Security at Heilongjiang University. In contrast, at the graduate level, the Modern Cryptography course consists of 48 contact hours when taken by academic master's students in Cybersecurity but only 32

contact hours when taken by professional master's students. The reform has not added any additional scheduled contact hours. Foundational diagnostic activities, expanded experiments and literature reading are done online on platforms like Chaoxing Learning, whereas in-class time focuses more on conceptual clarification, experimental instruction, case-based discussion and presentation of learning outcomes.

The design-based action research approach was used in the study and involved four steps which are intervention design, small scale pilot implementation, information gathering, and reflection review and iteration improvement. At the intervention design step the curriculum chain and task maps were formulated. At the pilot implementation step, differentiated learning tasks, research-based instruction cases and instruction manuals on how to use artificial intelligence were applied. At the data collection step, information was gathered through the basic assessments, laboratory reports, logs of code execution, course papers, logs of activities on the learning platform and interviews. In the reflective review step, course contents and assessment structure were improved using common mistakes, the performance of tasks and observations by instructors.

2.2 Research Questions, Reform Components, and Evidence Sources

In order to elucidate the relationship between the research questions, reform components, evidence sources and the extent of the conclusion, this paper developed a three research questions-three reform components-three evidence categories framework as indicated in Table 1. Every reform component was matched with its main evidence sources. The results were confined to the possibility of implementation, reproducibility and verifiability of the evidence without drawing conclusions on whether it led to improvements in student competencies or research outputs.

Table 1. Correspondence among Research Questions, Reform Components and Evidence Sources

Research Question	Reform Components	Primary Evidence	Scope of Conclusions
Continuous progression across undergraduate and graduate education	Three-level curriculum chain; differentiated tasks; differentiated pathways for academic and professional master's students	Task maps; code artifacts; laboratory reports; interviews	Implementation feasibility; no inference of competency improvement
Pedagogical transformation of research outcomes	Selection–adaptation–implementation–feedback mechanism	Instructional cases; reproducible experiments; feedback records	Reproducibility; no inference of increased research outputs
AI integration and assessment	AI integration throughout the instructional process; AI-use guidelines; process portfolios	AI-use statements; process portfolios; assessment rubrics; learning-platform activity logs	Evidence verifiability; platform click counts are not treated as indicators of student competency

2.3 Data Sources and Boundaries for the Use of Artificial Intelligence

The data were divided into four types which were learning outcome data, practical process data, learning process data, and interview and observation data. The assessment included cross-validation between instructor ratings, peer assessments, and original process records, whereas click counts on the online learning platform were considered process evidence only. It was necessary to apply the concepts of data minimization and anonymization in the implementation of artificial intelligence to the work of students. The use of AI was allowed as a conceptual explanation, code debugging advice, organizing literature search leads, as well as language editing but students were not allowed to submit unverified AI generated material in a direct manner. All code must be executed and verified, literature citations had to be checked with the original sources, and conclusions regarding security should have been backed up with experimental or theoretical findings.

3. Literature Review and Research Gap

The other existing works include the exploration of the online PAD Class [1], the project-based approach to teaching [2], the tiered experimental method of instruction [3], and the evaluation of outcome-based education (OBE) [4], and the combination of science and education [5]. Newer studies have also analyzed the use of generative artificial intelligence in personalized and adaptive learning [6][7][8]. Nevertheless there are three important limitations: (1) most of the current studies consider a particular level of education and seldom discuss, in an integrated undergraduate-graduate context, the joint issue of inequalities in the foundation knowledge of students, theory-based training of academic master's students and engineering-based training of professional master's students; (2) incorporation of the findings of research into classroom teaching tends to depend on the experience of individual teachers and it is not always accompanied by a systematic and ongoing process that includes the stages of selection, pedagogical adaptation, classroom application, and feedback; (3) current applications of artificial intelligence mostly emphasize question answering, exercise help or coding help, whereas learning diagnosis [9], experiment records, research-oriented reading, and assessment evidence have not been incorporated into the closed-loop system [10]. Therefore, this paper suggests the introduction of a reform model focusing on the curriculum chain, which is based on the pedagogical transformation of research results and which is enhanced by the use of artificial intelligence and process-oriented assessment.

4. Practical Challenges in Curriculum Reform

(1) There are significant differences in the fundamental knowledge of students and insufficient continuity between undergraduate and graduate education. The mathematical and programming background of students varies greatly depending on their disciplinary background. In the same instructional framework, some students can have difficulties with keeping up with the rest, and other students can experience a low level of difficulty in the course. Undergraduate students are supposed to know the algorithmic design structures; in a graduate course, however, they are supposed to gain more insight into the concepts of the

security model, attack model, and engineering limitations. If transitional tasks are not carefully planned, it may be necessary to re-visit already taught foundational material and students will learn the same things again through remedial teaching. Furthermore, the specific goals of education of academic master programmes, which focus on theoretical analysis, and professional master programmes, which focus on engineering practice, are not sufficiently considered in the course tasks and evaluation criteria.

(2) It is challenging to convert research findings into repeatable experiments. Symbolic derivations, experimental environments, and security premises discussed in research papers are meant to be read by experts and hence not suitable to be used as a teaching material. If research issues are not rephrased into pedagogically acceptable questions, broken down into smaller learning problems, and the experimental setting is not packaged, learners can be restricted to reading and comprehending the findings of the report instead of coming up with independently verifiable results.

(3) The implementations of AI are still scattered and lack sufficient assessment evidence. Artificial intelligence could enhance the effectiveness of information retrieval and code debugging but may come up with wrong algorithm, fabricated references, or insecure code. Currently, AI has only existed in isolation as an answer to single questions or as an aid to coding, and has not already been incorporated into the learning diagnostic system, experimental documentation, research-based reading, and process-assessment systems into a cohesive closed-loop system. It is thus crucial to make explicit what should be allowed under AI, what needs to be checked, the evidence of the process that needs to be kept and who owns the academic responsibility.

(4) Process-oriented assessment can be undermined by limited in-class hours. The discrepancy between the 48 contact hours offered to academic master's students and the 32 offered to professional master's students is such that the course should have a mix of core and extension tasks instead of just increasing the volume of material covered. Because the extension tasks are based on out-of-class engagement of students, there are cases when students cannot accomplish them in a situation where there is no tiered task design which consists of accessible mandatory tasks and advanced challenge tasks. In addition, process-oriented assessment may not offer a sound foundation of differentiated judgments of student performance without standardized scoring rubrics and consistent evidence trail.

5. Dual-Driven Curriculum Reform Framework of "Science–Education Integration + AI"

The reform framework includes four interconnected elements, namely the curriculum chain, the pedagogical transformation of research outcomes, AI integration, and five-dimensional process-oriented assessment. The components are connected in an objectives–content–tasks–evidence–feedback sequence. The curriculum chain defines competency progression, research outcome transformation gives real-world problems, AI facilitates the learning and practical tasks, and assessment mechanism produces evidence and feedback that improve instruction.

5.1 Developing a Three-Level Curriculum Chain

The three-stage curriculum chain consists of three phases, namely, undergraduate foundations,

undergraduate-graduate articulation, and advanced graduate research training. As depicted in Table 2, these stages are associated with the concept comprehension and algorithm reproduction, mathematical tools and attack analysis, and authentic problems and solution validation respectively. The continuous development of the three stages is accomplished by more complex tasks based on the same core knowledge issues but the task demands are further divided among academic and professional master's students.

Table 2. Three-Level Curriculum Chain and Progressive Tasks in Modern Cryptography

Stage	Primary Objectives	Core Tasks	Evidence of Learning Outcomes
Undergraduate Foundations	Concept comprehension, algorithm understanding, and programming-based reproduction	Block cipher implementation; hash function application; key management exercises	Source code; execution results; basic laboratory reports
Undergraduate–Graduate Articulation	Mathematical tools, algorithmic structures, and attack analysis	Differential/linear cryptanalysis; analysis of protocol assumptions; case reproduction	Descriptions of attack conditions; security analysis reports; discussion records
Advanced Graduate-Level Research Training	Authentic problems, solution justification, and result validation	Lightweight cryptography; resource-constrained cryptography; privacy-preserving computation; post-quantum cryptography topics	Literature review reports; solution justifications; experimental data; course papers

5.2 Four-Stage Mechanism for the Pedagogical Transformation of Research Outcomes

(1) Selection of research outcomes. Research outcomes are chosen depending upon the clearness of security goals, technological readiness, industry relevance, teaching complexity, and reproducibility of the experiment, but the focus is on the research on the security of industrial Internet, border network defense, commercial cryptography and post-quantum cryptography. (2) Pedagogical adaptation. The research papers are divided into problem contexts, key knowledge points, minimum reproducible experiments and open-ended inquiry tasks and the appropriate instructional level is indicated per component. (3) Implementation of the classroom. Versioned teaching resources are developed through lectures, discussions, coding experiments, and course papers. (4) Iteration based on feedback. The abnormal observations, performance bottlenecks as well as the security-related issues are written down and these records are used to improve the next round of instruction.

5.3 Integrating AI into Learning, Practice, Research, and Assessment

At the learning stage, the learning platform suggests additional resources depending on the results of the pre-class assessment of the students. In the practical stage, AI is applied to help in explaining the error messages, offer debugging directions, and come up with alternative solutions to compare them with each other; students must retain key prompts, the history of the revision procedure, and outcomes of execution-based validation. In the research process, AI can be used to arrange literature search tips and contrast research questions, but it cannot replace reading primary sources or performing security proofs. In the assessment stage, teachers will be using the learning behavior data and experimental process records to determine where there are gaps in students' knowledge, whereas the number of platform clicks is not considered a measure of competency. Every application of AI is recorded in the process portfolio, indicating which AI tool was employed, the reason behind its employment, the main prompts, human editing, and findings after validation.

5.4 Establishing a Five-Dimensional Process-Oriented Assessment Framework

The five-dimensional process-oriented assessment framework converts course goals and objectives into process evidence that is collectible and verifiable consisting of theoretical knowledge, practical skills, research-oriented reading and engagement in tasks, innovation capability and learning behaviors. The evidence sources and recommended weighting of each assessment dimension are linked to particular dimensions of the training objectives of academic and professional master's programs, although this can be altered based on the different training objectives of the two types of master's programs. Academic master's students can be assigned greater weight for theoretical proofs and literature reviews, whereas professional master's students can be given more importance on system implementation and engineering documentation. Table 3 has a reference configuration of graduate level courses.

Table 3. Five-Dimensional Assessment Indicators, Evidence Sources, and Recommended Weightings

Dimension	Assessment Focus	Primary Evidence	Recommended Weight
Theoretical Knowledge	Concepts; security models; algorithmic structures	Periodic assessments; in-class analytical discussions; comprehensive final examination questions	20%
Practical Skills	Coding; debugging; interpretation of results; engineering standards	Source code; execution logs; laboratory reports; engineering documentation	25%
Research-Oriented Reading and Task Engagement	Literature reading; problem formulation and analysis; task participation	Literature review reports; task records; peer assessments	20%

Innovation Capability	Problem identification; solution design; justification of improvements	Open-ended tasks; course papers; oral defense records	20%
Learning Behaviors	Task performance; contributions to discussions; academic norms	Process portfolios; reflective logs; AI-use statements	15%

6. First-Round Pilot Implementation Plan

6.1 Differentiated Blended Project-Based Learning

Prior to the class, students prepare the foundational assessments and micro-lecture preparation online. The instructional activities in class emphasize the clarification of concepts, derivation of algorithms, case studies, and laboratory guidance. Post-class, students do code reproduction, literature reading and reflection on learning. PAD classroom discussions are used to study the assumptions of security, the conditions of attack as well as the trade-offs between different solutions, whereas the flipped classroom sessions are used to share research-adapted teaching cases and group experiments. Project-based tasks are structured into four steps which include requirement analysis, choice of cryptographic scheme, implementation and validation and security evaluation. Every module contains both the foundational mandatory tasks and extension challenge tasks.

6.2 Course Modules and Hierarchical Tasks

The course material has been divided into six modules. Every module contains both undergraduate level tasks and graduate level tasks. The undergraduate tasks are about usage of tools, algorithm reproduction, and basic projects, and the graduate tasks are about security analysis, solution justification, engineering deployment, and integrated implementation, as presented in Table 4.

Table 4. Course Modules, Core Contents, and Tiered Tasks

Module	Core Contents	Undergraduate-Level Tasks	Graduate-Level Tasks
Foundational Theory	Discrete mathematics, number theory, and programming foundations	Tool utilization and algorithm practice	Reading and analysis of security models and proofs
Cryptographic Algorithms	Symmetric encryption, public-key encryption, digital signatures, and hash functions	Algorithm invocation and structural reproduction	Security analysis, performance comparison, and algorithm improvement
Protocols and Security Proofs	Authentication, zero-knowledge proofs, and secure multi-party computation	Analysis of objectives and attack conditions	Security assumptions, attack models, and proof strategies

Cryptographic Engineering	Key management, interfaces, testing, and engineering specifications	Interface implementation and key lifecycle exercises	Industrial deployment and engineering documentation
Advanced Topics	Post-quantum cryptography, privacy-preserving computation, blockchain, and homomorphic encryption	Concept mapping and case study reading	Literature reviews, solution justification, and experimental validation
Comprehensive Practice	Industrial Internet, border network protection, and commercial cryptography	Foundational projects and security documentation	Requirement analysis, system implementation, risk assessment, and project defense

6.3 Teaching Case: Key Management in the Industrial Internet

With the use of key management as the case study in industrial Internet devices, students learn to recognize assets and threats related to devices, communication links and management platforms and formulate security goals such as confidentiality, integrity, authentication and availability. On the basis of device resource limitations, students choose suitable cryptographic algorithms and key update schemes and conduct a minimal reproducible experiment. Students evaluate the risk of key leakage, replay attacks and configuration errors and provide source code or configuration files, execution logs and security analysis reports. Task completion and result interpretation is what undergraduate students concentrate on mostly, while academic master students should also cover security models and theoretical analysis, and professional master students give more attention to interface calls, deployment procedures, and engineering documents.

6.4 Process-Oriented Assessment and Guidelines for AI Use

The course grade is made up of lab evaluations, group reports, electronic learning activities, and an end-of-semester cumulative assignment. Laboratory assessments involve the submission of source code, execution logs, and students' security reflections. Group reports assess how the literature is organized, how the problem is defined and how the team works together; Online activity logs are used only as process indicators; Final cumulative task focuses on major concepts, security analysis and integrative reasoning. In each teaching cycle, teachers document typical mistakes and repeated questions, and improve further teaching with brief lectures, sample code or additional experiments. The use of AI is included in the process portfolios and the assessment distinguishes between tool-generated outputs and students' own understanding and verification results.

7. Formative Evidence, Practical Constraints, and Reflections on the Reform

7.1 Formative Evidence and Scope of Conclusions

In the first-round pilot there was created a chain of evidence of objectives-tasks-process-outcomes-feedback. At the objective level, the study examined whether tasks for undergraduates, academic master's students, and professional master's students aligned with their respective training requirements. On the task level, the research analyzed the extent to which experiments, literature reading tasks, and open-ended problems could provide a manageable progression in difficulty. On the process level, it looked at the completeness of the source code, the execution records, discussion records, and AI-use statements. On the outcome level, the research addressed the issue of whether students had the ability to explain algorithms, security assumptions, and engineering trade-offs. In the feedback level, tasks were improved through interviews, teacher observations and peer ratings.

According to Table 1, the existing formative evidence allows making these observations: (1) The three-layered curriculum chain and tiered tasks show implementation possibility, enabling various level students to determine proper entry points to tasks. Tasks for academic and professional master students are starting to diverge but there is no proof of the amount of competency enhancement. (2) The four-step mechanism of transformation of research findings can produce at least one reproducible and assessable case of teaching, and versioned teaching materials, but it does not establish that the process has consistently produced research outputs. (3) The use of AI guidelines and process portfolios can create testable evidence, and the five-dimensional evaluation structure makes the assessment chain largely complete, but the evidence does not prove that AI has a significant effect on the quality of learning or academic integrity. These results of the paper are confined to the feasibility of the reform scheme, evidence collectability, and assessment chain completeness. The suggested framework is not considered to be equivalent to the evidence of instructional effectiveness.

7.2 Practical Constraints

The restricted time in class makes it essential to extend activities to depend on student participation outside the classroom which leads to the need to offer easily available obligatory tasks as well as more advanced challenge tasks. Literature verification, experimental reproduction, and responsibility tracking should be implemented due to the risks of AI such as errors, hallucination, and insecure generated code. Process-oriented assessment will add more work to the instructors; hence, standard rubrics, common case repositories, and division of tasks between collaborators are required to reduce duplicated work. The diversity in the self-directed learning abilities of students necessitates the provision of milestones, exemplary results, and regular feedback. Since the reform requires coordination between the learning platforms, laboratories, and research projects resources, it is necessary to define clearly the duties related to maintenance and update cycles.

7.3 Research Limitations

The present research is based on a curriculum reform at a single provincial university. As the first-round pilot has been carried out within a relatively short time, the report mainly focuses on the implementation path and formative evidence. Thus, it cannot be used to make any inferences about the long-term effects or generalize the results to all institutions of higher education. Future studies will include sample-size

data, control data, pre- and post-test results and inter-rater reliability analysis as well as students' subsequent learning performance, and will also explore how the use of AI affects the quality of learning and academic integrity.

8. Conclusion

Modern Cryptography is an important pillar that links undergraduate backgrounds, graduate-level professional learning, and research training programs in the field of cybersecurity education. In order to overcome issues such as the differences between students in their background knowledge, lack of undergraduate-graduate connections, inability to convert research results into teaching materials, and disjointed use of AI, this paper has formulated a reform model encompassing a three-level curriculum chain, four steps of transformation mechanism of research results, AI integration throughout the teaching process, and a five-dimensional process-based assessment framework. The alignment among teaching tasks, evidence, and assessment was also shown by the case of industrial Internet key management. This study does not equate the proposed reform design with demonstrated teaching effectiveness. Further studies are needed to confirm the appropriateness of tiered tasks based on the actual data of students and classroom records, improve the assessment rubrics of academic and professional master's students, and assess the ongoing transformation of course outcomes into teaching materials and research questions.

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