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Development and Instructional Organization of Teaching Cases for Complex Engineering Problems in the Measurement and Control Technology and Instrumentation Program

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Abstract: Solving complex engineering problems requires students to combine disciplinary knowledge when they analyze problems and compare possible solutions. They must also make engineering decisions. In the Measurement and Control Technology and Instrumentation program, some teaching cases still focus on isolated knowledge points. Technical pathways are often fixed in advance. Few engineering constraints are considered, and assessment often emphasizes final results. Measurement and control tasks usually involve knowledge-module interconnection, multiple constraints, solution openness, and iterative validation. This study uses these features to redesign conventional tasks as teaching cases for complex engineering problems. The redesign includes four stages: engineering context embedding, knowledge module coupling, incorporation of engineering constraints, and solution openness and evidence-based validation. Case development also addresses two issues. The first is which complexity factors from the original engineering task should be retained. The second is how these factors should be reorganized for classroom use. These two steps are termed the extraction of complexity factors and pedagogical restructuring. The teaching cases are organized into three levels: structured cases, semi-open cases, and open-ended complex cases. The three levels differ in four dimensions: knowledge-module interconnection, engineering constraints, solution openness, and validation requirements. For each level, the paper discusses task configuration, instructional organization, and process-based assessment. The approach links the development of complex engineering problem-solving ability to course-based teaching cases. It also keeps the instructional scope of each case clearly defined.

Keywords: Measurement and Control Technology and Instrumentation; Complex Engineering Problems; Teaching Cases; Task Transformation; Engineering Decision-making.

1. Introduction

Modern measurement and control systems are becoming more integrated and intelligent. They now involve multi-parameter sensing, information fusion, real-time processing, and system-level coordination. This change is also reflected in the Measurement and Control Technology and Instrumentation program. Students now face tasks beyond sensor use, laboratory operation, and parameter calculation. They need to understand links among sensors, circuits, data acquisition, signal processing, computation, and control. These technical elements often affect one another. Students therefore need disciplinary knowledge as well as technical judgment. They also need to make engineering trade-offs under specific conditions. This creates a clear teaching challenge. Learning tasks must help students develop the ability to solve complex engineering problems.

In measurement and control education, a problem is not complex simply because it involves difficult calculations. A large amount of technical content does not make it complex either. Project size alone is also not enough. Complexity often comes from the links among technical decisions. For example, the choice of measurement method can affect later signal processing. Requirements for accuracy, response time, cost, and reliability can also limit the available solutions. These links should therefore be reflected in engineering teaching.

Recent studies have examined complex engineering problem solving from cognitive and instructional perspectives. Sun et al. [1] studied the relationship between knowledge and concept spaces using C-K theory. Sun and Peng [2] examined cognitive processes in collaborative problem solving. They also discussed knowledge construction, critical thinking, reflection, and feedback. Li et al. [3] studied practical teaching and its links with competency objectives and assessment. Liang et al. [4] examined teaching content and integrated practical training in an embedded systems course. These studies show different ways to include engineering requirements in learning tasks.

Case-based teaching has also been used in several engineering courses. Wang et al. [5] introduced case discussion into an Internet of Things course. Lan et al. [6] combined multi-level practical activities with different teaching arrangements. Their approach supported students in analyzing engineering tasks. Shi et al. [7] proposed a double-helix teaching model. Recent studies have also focused on students' abilities and course knowledge organization. Hu et al. [8] discussed teaching reform from the views of systems thinking and practical ability. Zhang et al. [9] studied course development through key-question design and knowledge organization. These studies suggest that practical activities alone are not enough. Teaching should also consider problem presentation, knowledge connections, and the reasoning students must provide.

Relevant teaching reforms have also been carried out in Measurement and Control Technology and Instrumentation courses. Wang et al. [10] developed progressive experiments

for Sensor and Testing Technology. Their design considered both program characteristics and engineering applications. Sun et al. [11] revised the objectives, content, and teaching methods of Measurement and Control Instrument Design. Li et al. [12] introduced discipline-specific engineering problems into Signals and Systems. They also adjusted the teaching and assessment methods. Jin et al. [13] revised the theoretical content, classroom interaction, and practical work in Modern Instrument Design. Zhao et al. [14] restructured course content and introduced integrated experiments and diversified assessment in Sensor and Testing Technology. Yao et al. [15] proposed a progressive case-based teaching approach linked with discipline-specific courses. Their work also provides a reference for designing cases for complex engineering problems. These studies provide useful experience in connecting disciplinary knowledge with engineering applications. This paper focuses on redesigning conventional teaching tasks. The aim is to move beyond the simple application of established methods. The proposed approach has four stages: engineering context embedding, knowledge module coupling, incorporation of engineering constraints, and solution openness and evidence-based validation. The redesigned cases must also remain manageable within normal course conditions.

A realistic engineering setting does not by itself change the nature of a teaching task. A case may use an industrial context but still provide the sensor, technical pathway, and operating parameters. Students can then finish the task by following the given procedure. They do not need to compare alternative solutions. Combining knowledge from several courses also does not always create real connections among technical modules. The same problem can occur in large practical projects.

Teaching cases for complex engineering problems should focus more on the decisions made by students. The engineering context should affect the task requirements. A decision in one technical module may also affect other modules. Proposed solutions should be checked against engineering constraints and validation evidence. The following sections explain how conventional tasks can be transformed. They also discuss case levels, instructional organization, and assessment.

2. Characteristics of Engineering Problems and Basis for Case Transformation

2.1. Complexity Characteristics of Measurement and Control Engineering Problems

Measurement and control tasks often require several related technical decisions. A typical system may include measurement principle selection, sensor configuration, signal conditioning, data acquisition, information processing, and system integration. These stages often affect one another. Sensor range and sensitivity can affect the required signal amplification. Signal frequency characteristics can affect sampling settings and later processing. Higher sampling rates or data resolution also increase demands on transmission, storage, and computation. So task difficulty is not determined only by the number of knowledge points. It also depends on how decisions in one part affect other parts of the system.

Engineering constraints can make measurement and control tasks more difficult. Meeting basic functional requirements is only one part of system design. Accuracy, dynamic response, noise immunity, reliability, power consumption, cost, installation space, and maintenance may all need consideration. Improving one performance indicator may also affect another. For example, a high-sensitivity sensor may detect weak signals more effectively. However, its usable measurement range may be narrower. A higher sampling rate can preserve more signal information. It also increases the amount of data for transmission, storage, and processing. So optimizing one parameter is often not enough. A suitable solution must balance several performance requirements and engineering constraints.

A measurement requirement rarely has only one technical solution. Different measurement principles, sensors, data-acquisition platforms, and processing methods may all be feasible. Their suitability depends on accuracy, response time, implementation cost, and operating conditions. Selecting a solution is only one part of the engineering task. Its performance must also be checked through experiments, simulations, or data analysis. If the results are unsatisfactory, system parameters or the technical pathway may need adjustment. For teaching-case design, these features can be grouped into four aspects: knowledge-module interconnection, multiple constraints, solution openness, and iterative validation.

2.2. Limitations of Conventional Teaching Cases

An engineering context can make a teaching case more relevant to practice. But this does not mean students are solving complex engineering problems. In some tasks, the teacher has already defined the problem and provided the required conditions. The method may also be selected in advance. Students then follow the given procedure and obtain the expected result. Such tasks can still help reinforce concepts and basic technical skills. However, students have fewer chances to interpret engineering needs when key decisions are already fixed. They may also have limited opportunities to identify technical requirements or define the problem boundary.

A similar issue appears when too many technical decisions are made before the task begins. Teachers may specify the sensor model, circuit structure, sampling parameters, experimental procedure, and programming framework. This can make laboratory work easier to manage. However, students may not need to explain why one solution is better than another. They have less involvement in proposing alternatives, setting comparison criteria, and making technical choices. Knowledge separation across courses can cause another problem. Sensing, signal conditioning, data acquisition, and signal processing are often taught as separate topics. In real systems, these technical stages are closely connected and affect overall system performance.

Assessment also affects how students approach a teaching case. If assessment focuses mainly on the final result, students may concentrate on completing the prescribed procedure. They may pay less attention to the reasons behind a technical choice. They may also overlook engineering constraints and the evidence supporting the final solution. Teaching cases should give students opportunities to explain their reasoning and compare feasible solutions. Students should also discuss the limits of their results. These requirements should still match the course level and available teaching time.

2.3. Differences Between Conventional Teaching Tasks and Teaching Cases for Complex Engineering Problems

The main difference is not the length of the task or its operating difficulty. It is the way the problem is structured and how much students take part in solving it. Conventional tasks usually ask students to apply disciplinary knowledge and established methods correctly. Teaching cases for complex engineering problems require more than following a fixed procedure. Students need to examine the problem conditions and compare feasible technical options. They also need to justify their choices with calculations, experiments, simulations, or data analysis. Their decisions should consider uncertainty and relevant engineering constraints. Table 1 summarizes these differences.

Table 1. Main Differences Between Conventional Teaching Tasks and Teaching Cases for Complex Engineering Problems

Comparison dimension	Conventional teaching tasks	Teaching cases for complex engineering problems
Problem context	Specified directly in terms of knowledge points, laboratory procedures, or explicit requirements	Situated in real or typical engineering contexts; students must identify needs and key conflicts
Problem boundary	Conditions are largely complete and the problem boundary is explicit	Technical criteria and task boundaries must be further defined
Knowledge structure	A single knowledge point or a small number of knowledge points	Multiple disciplinary knowledge modules are interconnected
Engineering constraints	Few constraints, usually without changing the main technical pathway	Multiple concurrent constraints, some of which constrain one another
Technical pathway	Largely predetermined or based on a standard operating path	Multiple reasonable solutions requiring comparison, trade-offs, and justification
Validation method	Compared with theoretical values, standard answers, or prescribed outcomes	Evaluated through experiments, simulations, calculations, or data-based evidence
Learning focus	Completing the task correctly and mastering knowledge and skills	Problem analysis, solution justification, engineering trade-offs, evidence-based validation, and optimization

As Table 1 shows, teaching cases for complex engineering problems do not replace conventional knowledge training. Rather, once students have acquired an appropriate disciplinary foundation, the problem boundary, organization of knowledge, and basis for assessment can be changed so that a previously single, deterministic knowledge-application task gradually acquires greater engineering integration and technical openness. How to make this transformation is the central issue addressed in the following section.

3. Method for Developing Teaching Cases for Complex Engineering Problems in the Measurement and Control Technology and Instrumentation Program

3.1. Transformation Pathway from Conventional Teaching Tasks to Teaching Cases for Complex Engineering Problems

Transforming conventional teaching tasks into teaching cases for complex engineering problems is essentially a reorganization of problem structure, not a simple increase in the amount of knowledge involved or in task difficulty. In light of the characteristics of measurement and control engineering problems, the transformation is organized into four connected stages: engineering context embedding, knowledge module coupling, incorporation of engineering constraints, and solution openness and evidence-based validation, as shown in Fig. 1.

Engineering context embedding should affect the decisions made in a task, rather than merely provide a background for an existing exercise. Consider a temperature-measurement task. When students are assigned a sensor and asked to calibrate it, the choice of measurement method has already been made. The task changes if the teacher instead specifies the measured object, operating temperature range, installation conditions, response requirements, and allowable error. Students must then decide which measurement principle and technical arrangement are appropriate for these requirements. In this way, the engineering setting influences the technical decisions students need to make, rather than simply describing where a measurement might be performed.

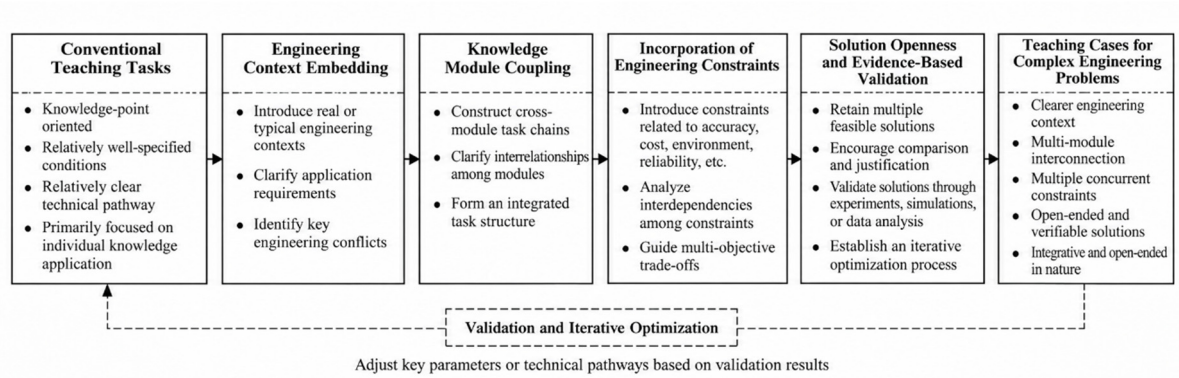


Fig 1. Transformation Pathway from Conventional Teaching Tasks to Teaching Cases for Complex Engineering Problems

Knowledge module coupling links decisions made at different stages of a measurement system. Sensor output characteristics affect the amplification needed in signal conditioning. Signal frequency characteristics affect filtering and sampling choices. The selected sampling rate also affects data transmission and later processing. A teaching case does not need to cover every area of the program. Students only need to examine links between at least two technical stages. They should also explain how one decision affects overall system performance.

Engineering constraints should be added only when they influence technical choices. These constraints may include accuracy, response speed, cost, power consumption, operating environment, and system reliability. Adding more constraints does not always make a case more complex. What matters is whether the constraints affect the choice of solution. For example, two solutions may both meet the basic functional requirements. They may still differ in cost, dynamic performance, and noise immunity. Students should explain what trade-offs they would make and why. The focus is on how engineering constraints affect decisions, not on meeting a long list of technical indicators.

Solution openness and evidence-based validation give students an opportunity to select and justify a technical pathway. Instead of providing every key component and parameter, the teacher can leave several feasible alternatives available for comparison. Students then need to examine the alternatives using appropriate calculations, experiments, simulations, or data analysis and explain whether the evidence supports the proposed solution. This also changes the basis of assessment. Obtaining the expected answer is no longer sufficient; students should be able to justify their technical choices and demonstrate that the selected solution meets the relevant engineering requirements.

The four stages describe the main transformation pathway. Validation and iterative optimization are not treated as an additional fifth stage, but as a feedback mechanism within the case development and teaching process. Where experimental, simulation, or data-analysis results reveal limitations, students can reconsider the selected parameters, technical pathway, or relevant task conditions. This allows the solution to be revised in response to evidence rather than treated as complete after its initial implementation.

3.2. Extraction of Complexity Factors

Engineering projects cannot usually be transferred into undergraduate courses without adjustment. They may involve extensive technical information, long development periods, and tasks beyond the knowledge and resources available to students. In developing a teaching case, the aim is therefore not to reproduce every part of an engineering project. Instead, the teacher needs to identify those aspects of the problem that are relevant to the intended learning objectives. Particular attention should be given to interactions between technical modules, relationships among engineering constraints, possible solutions, and the evidence needed to evaluate them.

The number of technical modules involved is not, by itself, a reliable indication of problem complexity. A task containing several independent modules may require little systems analysis. By contrast, a task involving only sensing, signal conditioning, and data acquisition may require considerable reasoning if a decision made at one stage changes the requirements at another. Engineering constraints should be examined in the same way. Accuracy, cost, and response speed may initially appear to be separate requirements, but a choice that improves one indicator can sometimes make another more difficult to satisfy. These relationships, rather than the simple presence of several requirements, are what create the need for engineering trade-offs.

Openness is another factor to consider when selecting complexity factors. If all components, parameters, and procedures are fixed in advance, students have little role in developing the solution. But removing too many conditions can make the task too open-ended for the course. A suitable case should leave enough room for students to make meaningful choices. At the same time, the task should remain manageable. The teacher also needs to decide how these choices will be evaluated. Possible methods include physical experiments, simulations, calculations, and existing data. The proposed case design uses four dimensions: degree of knowledge-module interconnection, intensity of engineering constraints, degree of solution openness, and validation requirements. These dimensions are used to distinguish cases at different instructional levels.

3.3. Pedagogical Restructuring

Identifying complexity factors is only the first step in case development. The engineering problem must then be adjusted to fit the course objectives and students' prior knowledge. This requires deciding which engineering conditions should be kept and which details can be simplified. Conditions that affect the choice or justification of a technical solution should usually remain in the case. For example, if the course aims to develop students' ability to select measurement solutions, the case should describe the measured object, measurement range, accuracy requirements, operating environment, and installation conditions. A full software development or communication task is unnecessary if it does not support this objective.

Task organization is also important. An engineering problem can be divided into smaller activities to make it easier to teach. However, these activities should remain connected. Students should be able to see how an earlier decision affects later choices. One possible sequence starts with identifying engineering needs and defining technical criteria. Students can then compare solutions, select parameters, and check the results through validation and assessment. This sequence works only when the decisions and results at different stages remain connected. Otherwise, the case may become a group of separate exercises rather than one integrated engineering problem.

The amount of information given to students should also match their stage of learning. For students who are still building their disciplinary foundation, the main technical pathway can be provided. Some parameters or components can still be left open for selection. As students gain more knowledge and experience, fewer conditions need to be fixed in advance. This gives them more room to compare alternatives and deal with interacting constraints. Technical choices should still be supported by evidence at every stage. Students can justify their decisions through parameter comparisons, calculations, experiments, or simulation results. Pedagogical restructuring therefore needs a balance between openness and feasibility. The case should preserve the engineering relationships needed for analysis and decision-making. It should also remain manageable within the course

objectives, available teaching time, and students' prior knowledge.

4. Layered Design and Instructional Organization of Teaching Cases

4.1. Layered Design of Teaching Cases

The complexity of a teaching case should be consistent with students' existing knowledge and engineering experience. A task involving several technical decisions may be suitable for students in the later stages of the program, but it may be too demanding for those who have only studied individual technical modules. Case difficulty should therefore not be increased simply by adding more work. It can instead be adjusted by changing the number and type of decisions that students are expected to make. In this study, teaching cases are divided into three levels: structured cases, semi-open cases, and open-ended complex cases. As shown in Fig. 2, the progression is described through four dimensions: degree of knowledge-module interconnection, intensity of engineering constraints, degree of solution openness, and validation requirements. These levels represent a gradual increase in the complexity of engineering decisions rather than three fixed categories of teaching activities.

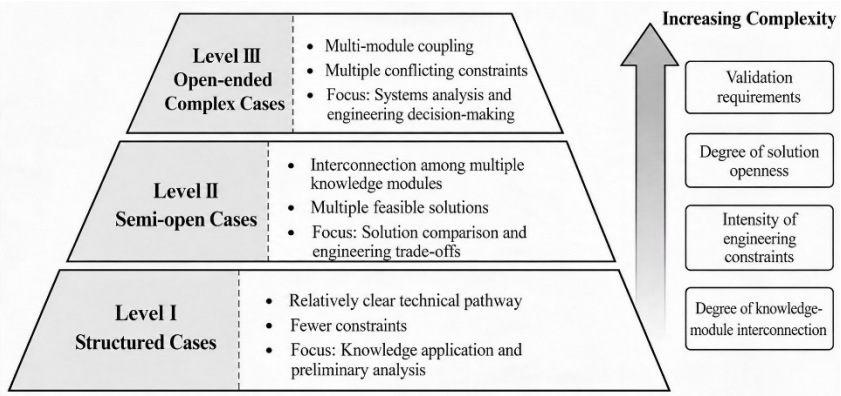


Fig 2. Three-Level Instructional Progression of Teaching Cases for Developing Complex Engineering Problem-Solving Ability

Structured cases are mainly suitable for students in the early stage of professional learning. The engineering context is clear, and the main technical pathway is mostly defined. Teachers can provide several key conditions. Students then analyze parameters, make limited technical choices, and verify the results. Compared with traditional experimental tasks, these cases add an engineering context and basic solution analysis. This helps students move from simple knowledge application to preliminary engineering analysis.

Semi-open cases are suitable for students who have learned several related areas of professional knowledge. Teachers provide the engineering objectives, basic technical requirements, and necessary constraints. Key devices and implementation methods are no longer fully specified. Students need to develop several feasible solutions and compare them under different performance and operating conditions. The focus shifts from whether the function can be achieved to why a particular solution should be selected. Solution comparison and engineering trade-offs therefore become important learning activities.

Open-ended complex cases are mainly used in comprehensive professional courses or for senior students. These cases include several related technical modules and may involve conflicting engineering requirements. Students need to identify problems, develop solutions, carry out validation, and make improvements with greater independence. Teachers do not provide a fixed technical pathway. Instead, they define the problem boundary, available resources, and assessment requirements. The three levels progress mainly through greater openness in the problem structure, not simply through larger tasks.

4.2. Case Task Configuration

Table 2. Example Configurations of Typical Measurement and Control Tasks

Task domain	Engineering conditions that can be introduced	Open design choices	Example configurable levels
Sensing and measurement	Range, accuracy, dynamic characteristics, environment, and installation conditions	Measurement principle, sensor type, calibration, and compensation scheme	Structured–Semi-open
Signal conditioning	Signal amplitude, frequency band, noise, power supply, and interference-immunity requirements	Gain, filter structure, isolation, and noise-suppression methods	Structured–Semi-open
Data acquisition	Sampling rate, resolution, number of channels, synchronization, and real-time requirements	Sampling parameters, acquisition platform, communication, and buffering strategy	Structured–Semi-open
Information processing and instrument systems	Computing resources, refresh rate, error sources, and human–machine interaction	Processing algorithm, hardware/software allocation, display, and diagnostic methods	Semi-open–Open-ended
Integrated measurement and control	Multi-module coupling, cost, reliability, maintenance, and extensibility requirements	System architecture, technical pathway, parameter configuration, and validation plan	Semi-open–Open-ended

The same teaching-case design approach can be used for different kinds of measurement and control tasks. Task selection should be based on the course objectives and on the technical knowledge that students have already acquired. Possible starting points include sensing and measurement, signal conditioning, data acquisition, information processing, instrument systems, and integrated measurement and control. However, the technical domain itself does not determine the

complexity of the case. The teacher also needs to decide which engineering conditions should be included, which technical decisions should remain open to students, and what evidence is required to support their proposed solutions. Table 2 shows how these elements can be combined in several typical measurement and control tasks.

A particular task domain does not have to be assigned to one case level. Its instructional complexity depends on the problem boundary, the engineering constraints involved, the decisions left to students, and the required form of validation. The same technical task can therefore be used at different stages of learning, provided that its conditions and expected outcomes are adjusted accordingly.

Data acquisition is a useful example. If the teacher provides the sampling rate, ADC resolution, and acquisition platform, students mainly configure the system and complete the required program. This task is close to a structured case. If students are instead given the signal frequency range, allowable measurement error, channel requirements, and update period, they must choose suitable acquisition parameters. They also need to examine how these choices affect data volume and processing load. The task then becomes semi-open. A more advanced case may add multi-channel synchronization, resource and cost limits, and a validation plan. Students must then consider how sampling, synchronization, processing, and available resources affect one another. The same technical domain can therefore support a higher-level teaching case for a complex engineering problem.

The same engineering context can also be used across different courses. Equipment condition monitoring is one example. In a sensing course, students can compare sensors and judge their suitability for a measurement task. In a signal-processing course, the focus can move to sampling decisions and feature extraction. In an integrated course, students may need to consider these stages together. They may also need to account for real-time performance, cost, and long-term reliability. The engineering context remains similar, but the task boundary changes with the teaching objective. The decisions required from students also change. This allows case resources to be reused across different stages of the curriculum.

4.3. Instructional Organization and Assessment

Teaching cases for complex engineering problems require a different classroom approach. The teacher should not provide every step-in advance. Students need enough information to understand the task, but key technical decisions should remain open. The teacher can define the problem boundary, explain the main engineering conditions, and offer guidance when needed. Teaching can then follow six related activities: context introduction, problem identification, solution development, comparison and justification, validation analysis, and assessment and improvement. These activities give a general sequence for the case. However, earlier decisions may need to be revised when new evidence appears.

At the start of the case, students need to understand the engineering object, operating conditions, and task requirements. They then convert the application requirements into technical criteria for design. Based on these criteria, students can develop possible solutions and compare their strengths and limitations. Each technical choice should be explained in relation to the given conditions. Calculations, experiments, simulations, or data analysis can be used to test the proposed solution. If the results show problems, students may need to adjust parameters or change the technical pathway. Teacher guidance is useful at these points. However, giving a complete solution too early can limit students' opportunities to develop engineering judgment.

Assessment should consider both the solution process and the final result. A working device or correct program output does not always show that students understand their technical choices. Assessment can examine how well students identify the problem and use knowledge from different modules. It can also consider how they compare solutions and deal with engineering constraints. The quality of validation evidence should also be assessed. Students should be able to explain the reasons behind their technical decisions. Different solutions can be accepted if they are technically sound and meet the task requirements. Assessment criteria should match the objectives of each course instead of using the same weights for every case.

5. Conclusion

Teaching cases for complex engineering problems should not be defined simply by the amount of work involved or the difficulty of individual exercises. Their value lies in giving students opportunities to identify engineering requirements, connect knowledge from different technical areas, compare possible solutions, and justify their decisions. These activities are particularly relevant to Measurement and Control Technology and Instrumentation, where sensor selection, signal conditioning, data acquisition, and information processing are often closely related. The design of a teaching case therefore needs to preserve the interactions among technical modules, engineering constraints, solution choices, and validation activities.

This paper presents a pathway for redesigning conventional teaching tasks as teaching cases for complex engineering problems. The pathway includes four connected elements: engineering context embedding, knowledge module coupling, incorporation of engineering constraints, and solution openness and evidence-based validation. Case development is further considered from two aspects, namely the extraction of complexity factors and pedagogical restructuring. To reflect differences in students' knowledge and engineering experience, the cases are organized into three levels: structured cases, semi-open cases, and open-ended complex cases. These levels differ in the degree of knowledge-module interconnection, the intensity of engineering constraints, the degree of solution openness, and validation requirements. The paper also discusses corresponding methods for task configuration, instructional organization, and process-based assessment.

The present study focuses on the design and organization of teaching cases rather than on evaluating their teaching effects. Quantitative evidence of improvement in student performance is not yet available because comparative teaching evaluations have not been carried out in specific courses. A useful next step would be to apply representative cases in courses such as sensing and measurement, data acquisition, or modern instrument design. Students' design records, solution reports, validation results, and assessment materials could then be analyzed to examine how the proposed case levels are related to their performance in problem analysis, solution justification, and engineering

decision-making. The results could provide evidence for further refinement of case content and classroom organization.

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