

Integrating Virtual and Physical Practice in Project-Based Industrial Robotics Education

Feng Hu

School of Robotics Engineering, Yangtze Normal University, Chongqing, China

Abstract: In Industrial Robot Technology and Applications course, even if a simulation is successful, it does not mean that students have fully mastered the concepts. At the same time, a high grade on a group assignment does not necessarily mean all members possess a high level of capability. For this problem, this paper proposes a project-based teaching reform framework for the Industrial Robot Technology and Applications courses. In this framework, the course projects extend from fundamental knowledge points to complex projects, and simulation-based teaching is conducted for a wide range of practical scenarios. In the teaching process, the simulation platform is primarily ABB RobotStudio, and robot target verification is conducted on an actual industrial robot integration system, promoting the effective integration between simulation models and real industrial robots. Based on this, the teacher needs to instruct students to compare the difference between expectations and actual operational results, and analyze the deviation reason, as well as adjust the teaching plan. Finally, course evaluation not only focuses on the final team project results but also comprehensively evaluates students' understanding of basic principles, the code debugging process and individual performance.

Keywords: Industrial Robotics; Project-Based Learning; Virtual and Physical Laboratories; Robotstudio; Engineering Education

1. Introduction

Industrial robotics education brings together concepts that students must eventually use in a working robot workstation. A coordinate frame determines how a target is expressed; a motion instruction affects the path to that target; and program conditions determine when the movement is permitted. Teaching these topics separately can make their relationships difficult to

recognize. The Industrial Robotics Technology and Applications course aims to help robotics engineering students move from executing individual commands to explaining, implementing and checking a workstation solution.

If the educational value of laboratory activities is to be assessed, then the activities must have explicit learning goals. Feisel and Rosa [1] state this when considering undergraduate engineering laboratories. In industrial robotics, finishing a sequence of movements is just one of the desired learning steps. Students must also explain their decisions, explain unexpected actions and whether a suggested correction fixes the reason behind an issue. These outcomes require evidence to be provided in addition to achieving a successful final demonstration.

Project-based learning provides a way to organize such work around a coherent task. Kokotsaki et al. [2] review the approach across educational settings and discuss the conditions that support its use. In robotics engineering education, Navarro Arcas et al. [3] examine an international online project-based course, offering a relevant example of collaborative project work and competence development. In the present course, handling and palletizing tasks can connect coordinate configuration, motion programming, sequence control and debugging. Their educational value depends on the guidance and feedback available during the project, as well as on what students are expected to explain at its conclusion.

Virtual and physical laboratories offer different opportunities for learning. De Jong et al. [4] discuss their complementary roles in science and engineering education, while Brinson [5] reviews learning outcomes in virtual, remote and hands-on laboratories. Previous studies have examined the combination of real and virtual experiments and the design of virtual laboratories for blended learning [6,7]. These studies support the adoption of a well-considered mix of blended learning environments but do not indicate that any specific implementation sequence is universally

applicable to all courses or tasks. For a laboratory activity to be evaluated in terms of its educational value, there must be some learning goals that are explicitly stated. Feisel and Rosa [1] state this in their article on undergraduate engineering laboratories. In industrial robotics, the goal of the learning is to finish a sequence of movements. Students also must explain their decisions, explain unexpected behaviors and decide if a suggested correction will solve the problem. These outcomes require evidence other than that of a successful final demonstration.

In this course, RobotStudio can be used as a tool for exploring the behavior of the model workstation, program logic, and motion behavior. Actual physical equipment includes installation needs and operating instructions and will need to be reviewed at the workstation. One pedagogical question is how students should make use of the information in these two environments. A mismatch between simulated and actual results may give rise to an explanation and a specific test, or it might result in a series of parameter changes without insight. Students should be asked to state the rationale behind the selection of a check or a correction during the course activities and when evaluating.

Feedback is at the heart of this difference. Based on that, Nicol and Macfarlane-Dick [8] connect formative assessment with students' capacity for self-evaluation and feedback utilization for improving their performance. In robotics projects this would involve looking at why the program had to be changed, the proof that led to the discovery of the fault, and how much independent work the student did. These aspects of learning cannot be adequately assessed through a group demonstration alone.

New research has given more detailed suggestions on how to teach courses in robotics. In [9] Haraguchi describes a project-based program for practicing basics of robot system integration. Ishitsuka et al. [10] state a collaboration between industry and academia scheme in which the robot tasks are coupled with evaluation of the robot by the company's engineers. Li and Liang [11] review the positive effects of virtual laboratories in engineering education and the restrictions to their substitute for the hand-on laboratories. Deriba et al. [12] discuss accessibility in the context of virtual laboratories and point to instructional design, the availability of content and interaction support. These studies are used to select complete

workstation tasks, to allocate virtual and physical tasks and to prepare usable learning resources in the current framework.

This paper proposes a reform framework with continuous project tasks as the main thread, supported by practice combining the virtual and the real, and assesses students' personal abilities through independent operational steps. To achieve effective synergy between practical teaching and course evaluation, this paper further investigates the correspondence and operational deviations between a simulation model and an actual robot, explores specific teaching projects and assessment methods, and analyzes the conditions required for the implementation of reforms.

2. Teaching Philosophy and Reform Framework

2.1 Key Issues to Be Addressed

There are some issues worth paying attention to in the teaching of Industrial Robotics courses. On the one hand, knowledge points are scattered across different chapters, such as mechanical mechanism, actuators and sensors. Students only gain a superficial understanding of the subject matter, and it is difficult to understand relationships between the key points in each chapter. On the other hand, even though simulation in projects runs perfectly, it does not mean that students sufficiently understand the differences between a model and a real robot. For example, factors such as model simplification may affect actual operational results, which might be overlooked in simulation-based teaching.

2.2 Intended Learning Outcomes

The emphasis of this framework is on developing students' knowledge application, programming and debugging, and engineering practice. As for applying knowledge, it involves students selecting the appropriate coordinate system and movement instructions based on different tasks and explaining the reasons for their selection. With regard to programming and debugging, it focuses mainly on the rationality of the end effector's actions and the correctness of program execution. In terms of solving engineering problems, it needs to emphasize analyzing the reason for the failure and revising solutions. Safe operation of equipment and team working should also be considered in the Course Evaluation.

2.3 Connecting Virtual and Physical Practice

Integration is defined at three levels. Model correspondence requires the relevant features of a virtual model to be checked against the physical robot, tool, workpiece and layout. Task continuity means that virtual analysis and physical validation address the same operating requirements. Feedback requires observations from practice to lead, where appropriate, to changes in the model, program or explanation. Consistent with the review by Wörner et al. [6], the sequence of activities should follow their learning purpose and the information each environment can provide.

Figure 1 shows the proposed relationship. A

workstation task establishes the learning goals. Virtual analysis produces a solution and predictions about its behavior; physical validation supplies observations under actual conditions. Students compare the two, investigate discrepancies and revise the relevant part of the solution before checking it again. Explanations, independent work and performance under changed conditions provide assessment evidence. Instructors can then use that evidence to refine tasks, resources and guidance. Physical validation in this framework presupposes suitable equipment and operating conditions, as discussed in Section 4.

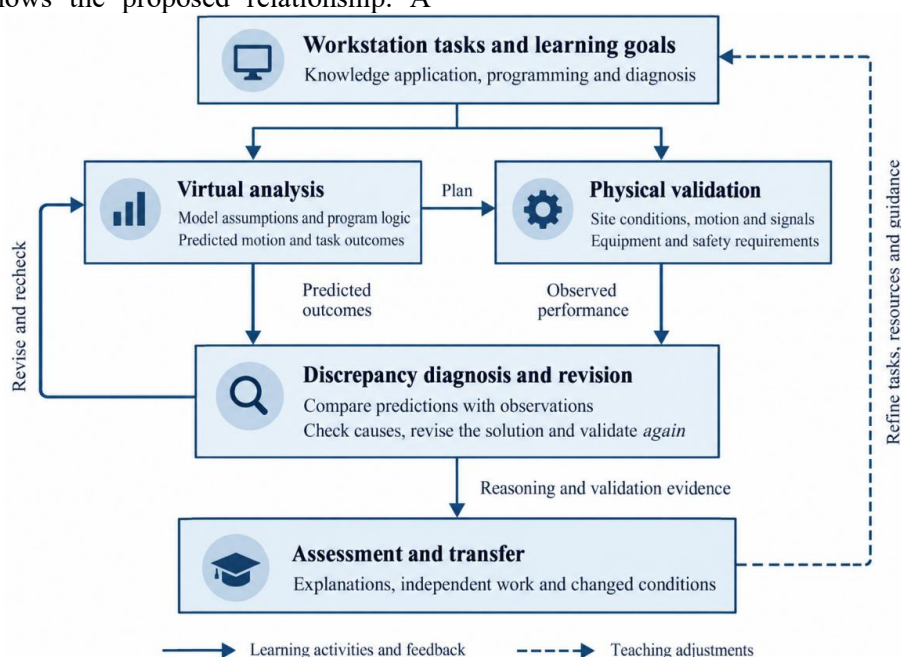


Figure 1. Proposed Framework Linking Workstation Tasks, Virtual and Physical Feedback, and Assessment

3. Curriculum and Assessment Reform

3.1 Organizing Course Content around Workstation Projects

At the foundational application stage, it primarily works by changing conditions of tool posture and target location to help students understand the relationship between programming and robot motion. At the industrial robot system integration stage, the project will involve tool configuration and workpiece positioning. At the same time, the project will incorporate path planning and signal interaction, which require students to fully consider the coordinated operation of all components. At the application migration stage, by changing the palletizing requirements and workstation layout, the project encourages

students to analyze the utility of the existing program and complete the corresponding revisions.

Within the pedagogical framework, each chapter has a rigorous logical connection. Program code and model construction from preceding chapters will lay the foundation for subsequent chapter tasks. However, it is necessary to pay attention to the conditions under which they apply. During the teaching process, teachers should explain relevant knowledge by combining with practical problems encountered by students, facilitating their understanding of the impact of different operations on task execution on a workstation. At the same time, students need to explain the rationale for any adjustments to their proposals, to prevent students from treating successful program execution as the sole learning objective.

Figure 2 presents task arrangements for each stage and corresponding learning requirements.

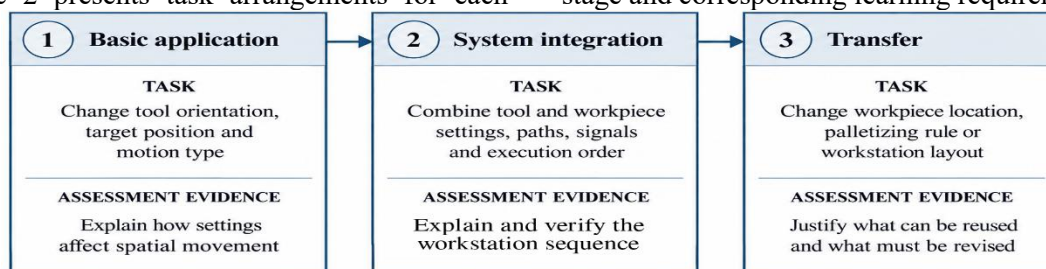


Figure 2. Progression of Workstation Projects and the Reasoning Expected at Each Stage.

3.2 Developing Corresponding Practical Resources

The teaching resource of projects should be designed based on the teaching content and robotics teaching equipment. These are basically RobotStudio simulation models, technical documentation of the equipment and relevant operating instructions. Task programs can be applied to on-site verification, if physical equipment is available. If the simulation models have to be simplified, then it should be explained to the students what has been omitted, i.e. the difference between the model and the real apparatus.

The configuration of the coordinate system plays an important role on workstations in modeling and debugging programs. Work object coordinate system should be aligned with the actual position of the work object, and the tool coordinate system should be consistent with the actual installation position of the end-effector. In RobotStudio, the position of the workpiece can be precisely determined in the model, but the position of the real equipment still needs to be verified. If there is any discrepancy between the two, then the robot may not perform as simulated.

Task specifications, initial programs and case studies of typical faults can be provided in the teaching material. The instructor first shows troubleshooting techniques, and then encourages students step by step to do analysis and debugging themselves. For example, if the tool coordinate system is set up incorrectly, the position of the tool may be incorrect; if the input signal is abnormal, the program may be unable to continue execution. Case studies can be added to the teaching resources, according to topics that arise during the teaching process, to continuously enrich the teaching content.

3.3 Using Discrepancies to Support Engineering Reasoning

Students can check their theoretical knowledge

against the actual results in the simulation process and actual operation. Students should make educated guesses/estimates before they perform a task to understand what they think the result is going to be and why. In the virtual analysis this means explaining the effect of the coordinate system on the interpretation of the target object and why a certain approach path fits a given task. Different settings are compared to build up relationships between parameters, motion and results of a task. The relationships between these activities, practical verification and assessment evidence are shown in Figure 3.

For physical validation, appropriate equipment, supervision and safety measures must be in place. After checking the program and the operating range, validation can cover important positions, action order & signal responses. A grasping position error is shown to explain the reasoning that is desired, but not to assume there is one reason. Students can view the tool frame, the workpiece frame and the actual workpiece placement and choose from checks which can lay out the distinctions between the possible explanations. Students should say what they think is the problem and what they would expect to happen before they make their fix. They should then make a comparison between that prediction and their new observation.

After a correction has been made, students should explain whether the problem was solved, whether the original diagnosis is still believable, what changed, and what conditions would make a new check necessary. Revealing whether they can apply the reasoning independently can be achieved by a subsequent task with a different location of the workpiece or target orientation. Assessment therefore considers both task completion and the student's explanation of the observed behavior. Figure 4 illustrates this diagnostic sequence for a grasping position error; it is an instructional example, not a reported experimental result.

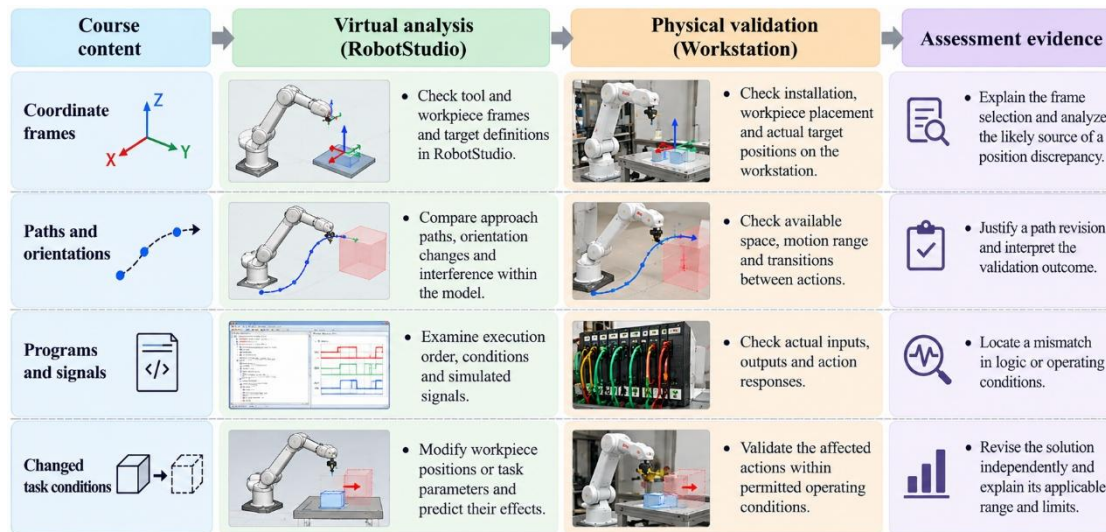


Figure 3. Alignment of Practical Activities and Assessment Evidence.

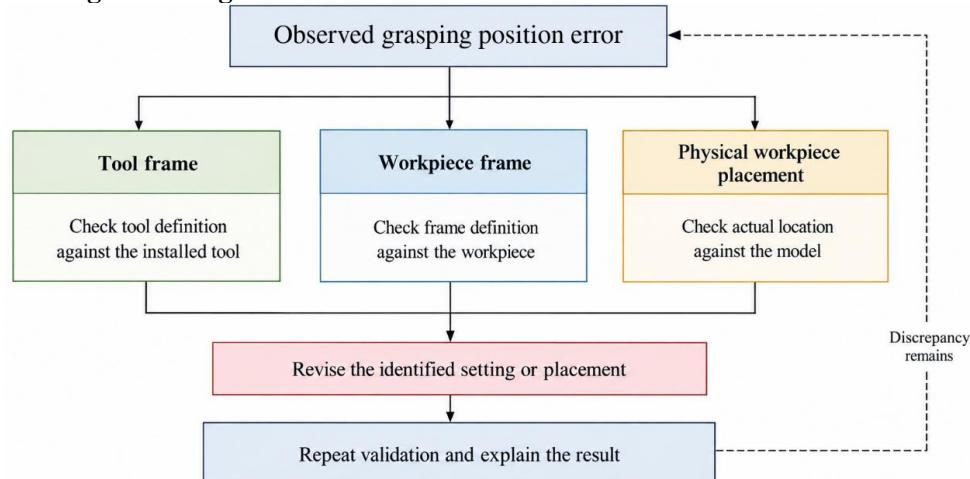


Figure 4. Alternative Causes, Diagnostic Checks and Repeated Validation for a Grasping Position Error

3.4 Assessing Reasoning alongside Project Outcomes

Assessment should be visible from the outset of a project, in terms of the learning outcomes that it is intended to achieve. Feedback should highlight a specific question and/or change for the next time that the student tries, as suggested by Nicol and Macfarlane-Dick [8]. While the finished product on workstation is still important, it is taken in conjunction with the decisions that led to its creation.

Instructors review task analysis by the students to evaluate their identification of operating conditions and reasoning for important decisions. Programs are evaluated on logical completion and accuracy of task completion. Debugging records should include the problem, suspected cause, selected check and interpretation of the outcome of the check. Some questions pertaining to the technical explanations should also be left

unanswered. Safe operating practice is evaluated during validation and unsafe practices are corrected prior to resuming work.

Evidence may include solution descriptions, chosen version(s) of programs, key debugging records and demonstrations. Materials must be complemented by individual explanation and demonstration of important operations in a group project. Students may need help even if they are able to copy the group plan, when it comes to explaining or changing the plan. Single assessment allows different situations to be distinguished from each other, without neglecting the importance of collective learning.

Important professional judgments are made by the teacher, and self-evaluation and peer feedback allow for reflection and discussion of individual contributions. Feedback needs to clearly indicate what needs to be done to improve and be reviewed after students have made the required changes. Issues that keep occurring can also

shape the improvement of teaching materials and teaching techniques, and tie the evaluation of work back to the constant optimization and improvement of the course.

4. Implementation Considerations and Limitations

4.1 Matching the Framework to Available Facilities

The context of the course is a program of robotics engineering in which ABB RobotStudio is employed for simulation activities. Implementation needs to make a distinction between what can be done in software and what needs physical equipment. Model construction, program analysis and virtual motion checks are possible in the simulation environment. The appropriate hardware, supervision and safety set-up is necessary for the verification of actual coordinates and the behavior of the tools and workstation.

Documentation of the equipment and recorded cases can assist students to explore model assumptions and prepare for validation. They are not as conclusive as direct operation. The proposed integration thus requires having access to a physical workstation for the checks requiring it. Firstly, correspondence between the robot, tool, blank and task requirements should be set up when developing resources, and then the model should be simplified and the verification procedures at the workstation should be identified. This is in line with Li and Liang [11] who, in their meta-analysis, found that virtual laboratories can be used as a supplement, whilst also recognising the limits of their use to replace hands-on work.

4.2 Keeping Assessment Feasible and Interpretable

It can be burdensome for students to record all the processes while they are operating. Documentation should be brief – initial solution, subsequent revisions, and why? – the focus is on the decision making process, not the amount of documentation. Comparisons between stages should be based on tasks with similar knowledge demands and complexity and the assessments should be based on similar criteria. More demanding extension tasks should be assessed separately (see above).

Groups can turn roles, give explanations and do personal checks of the important points of the program to get a better picture of participation

within groups. Documenting if the work was self-directed, prompted or assisted provides valuable background information for the final product. If self-evaluation and peer feedback are in conflict but there is general agreement from the teacher, the following simple questions or activities can be used to clarify understanding. This type of audit should clear a particular doubt not create further documents.

4.3 Revising the Course and Evaluating the Framework

Any changes to course tasks should be made based on problems arising during teaching. For instance, if students struggle to comprehend coordinate systems, then more comparative examples can be added. The actual configuration should be checked, as well as the modeling assumptions, if the simulations and real workstations differ. If the students are too dependent on the teacher, the teacher's directions can be slowly decreased to get students to solve the problem independently. Group projects may also involve varied participation, which may necessitate some changes in task allocations and individual assessments. Project completion rates alone cannot necessarily identify these issues.

Following the changes, they should be reviewed based on evidence from the next teaching activities. The focus of the evaluation should be on how the original problems have been addressed and not on the results alone. This enables teachers to see what adjustments are helpful and what further adjustments are needed. Task difficulty, students' prior knowledge and equipment conditions should also be taken into account when making comparisons between the results of different projects. Evidence gathered in a similar context will be more robust for judging the impact of the changes in teaching and assessment in supporting students' skills in independent thinking and problem-solving.

5. Conclusion

Based on Industrial Robot Technology and Applications, this paper proposes a reform plan for project-based teaching. Teaching content revolves around typical tasks for industrial robot workstations, such as palletizing and handling, and integrates chapter knowledge points into each project. In this process, the proposed framework focuses on establishing a correspondence between a virtual model and a physical robot. Teachers should instruct students to compare

expected results with actual operational outcomes, and solve the problem step by step through plan adjustments.

References

- [1] Feisel, L. D., and Rosa, A. J. The role of the laboratory in undergraduate engineering education. *Journal of Engineering Education*, 2005, 94(1): 121–130. DOI: 10.1002/j.2168-9830.2005.tb00833.x.
- [2] Kokotsaki, D., Menzies, V., and Wiggins, A. Project-based learning: A review of the literature. *Improving Schools*, 2016, 19(3): 267–277. DOI: 10.1177/1365480216659733.
- [3] Navarro Arcas, A. R., Llorca Schenk, J. M., Jara, C. A., et al. Educational impacts on robotic engineering students of an international online project-based learning course. *Education Sciences*, 2024, 14(12): 1305. DOI: 10.3390/educsci14121305.
- [4] de Jong, T., Linn, M. C., and Zacharia, Z. C. Physical and virtual laboratories in science and engineering education. *Science*, 2013, 340(6130): 305–308. DOI: 10.1126/science.1230579.
- [5] Brinson, J. R. Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. *Computers & Education*, 2015, 87: 218–237. DOI: 10.1016/j.compedu.2015.07.003.
- [6] Wörner, S., Kuhn, J., and Scheiter, K. The best of two worlds: A systematic review on combining real and virtual experiments in science education. *Review of Educational Research*, 2022, 92(6): 911–952. DOI: 10.3102/00346543221079417.
- [7] Antonelli, D., Christopoulos, A., Laakso, M.-J., et al. A virtual reality laboratory for blended learning education: Design, implementation and evaluation. *Education Sciences*, 2023, 13(5): 528. DOI: 10.3390/educsci13050528.
- [8] Nicol, D. J., and Macfarlane-Dick, D. Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education*, 2006, 31(2): 199–218. DOI: 10.1080/03075070600572090.
- [9] Haraguchi, D. Development and educational implementation of a project-based learning program for practicing fundamentals of robot system integration process. *Journal of the Robotics Society of Japan*, 2024, 42(3): 211–214. DOI: 10.7210/jrsj.42.211.
- [10] Ishitsuka, K., Takahashi, T., Yasunaka, T., and Takezawa, S. Implementation of “Robot Sler” education, including machine IoT, through academia-industry collaboration between local businesses and the National Institute of Technology. *Journal of JSEE*, 2024, 72(2): 2_7–2_11. DOI: 10.4307/jsee.72.2_7.
- [11] Li, J., and Liang, W. Effectiveness of virtual laboratory in engineering education: A meta-analysis. *PLOS ONE*, 2024, 19(12): e0316269. DOI: 10.1371/journal.pone.0316269.
- [12] Deriba, F. G., Saqr, M., and Tukiainen, M. Assessment of accessibility in virtual laboratories: A systematic review. *Frontiers in Education*, 2024, 9: 1351711. DOI: 10.3389/educ.2024.1351711.