



Research Paper

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The Role of Reflection-Informed Learning and Instruction in an Introductory Physics Course for Engineering and Science Students

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ABSTRACT

This research explores the role of reflection-informed learning and instruction on students' learning in an introductory physics course. Participants of this quasi-experimental study were 199 engineering and science students (n=105 in the control group and n=94 in the intervention group). Students in the intervention group were instructed to reflect on their learning experiences after each lecture using the CourseMIRROR mobile application, while students in the control group did not. To answer our first research question (i.e., Did the students in the intervention group perform better than ones in the control condition?), we conducted Kruskal-Wallis tests, and results showed that the intervention group showed significantly better academic performance than the control group. To answer our second research question (i.e., Are the quantity and the quality of student reflection a significant predictor of academic performance?), multiple linear regressions were conducted. We found that the number of reflections was a significant factor in predicting a learner's academic performance, while specificity of reflections was not. Our study extends the existing literature on the impact of prompting student reflection in learning to a relatively underexplored context of large-size, lecture-oriented classrooms. Also, our study found that intervention in the form of encouraging students to reflect more often on their learning experiences can lead to improved academic performance. By evaluating reflection quantity and quality, our research contributes new insights into how these aspects influence academic performance. Lastly, our study adds to previous findings on utilizing mobile applications to support reflection activities in large classrooms by investigating their application in a traditional, lecture-based physics course.

1 INTRODUCTION

Reflection is a generic term for “human activities in which people recapture their experience, think about it, mull it over, and evaluate it” (Boud, Keogh, and Walker 1985, 19). Reflection can be classified into reflection-in-action and reflection-on-action (Schon 1983). Reflection-in-action is metacognitively reflecting on one’s learning or behavior during learning, while reflection-on-action happens after learning or learning activities are completed (Schon 1983). In the context of undergraduate education, many science and engineering courses are taught in lecture-based format, especially in introductory courses where hundreds of students enroll (Owens et al. 2017). Reflection-in-action tends to be difficult to implement in this course as it may require significant changes in existing instructional methods. Reflection-on-action can be implemented individually outside the classroom after taking a lecture, so they seem easier to implement than reflection-in-action. Still, just with traditional instruction tools, promoting reflection-on-action in a large classroom can be challenging due to the logistics involved in collecting a large number of student reflections and assessing the relevance and quality of each reflection in a timely manner. By using digital technology accessible to individual students and instructors, such as a mobile application, individual reflection activities can be incorporated into a course more easily.

Reflection-informed learning and instruction (RILI) is a pedagogical model that encourages students to reflect on their learning in courses using technology and uses their reflection-on-action data to improve instructional strategies (Menekse 2020). The RILI model can be useful in undergraduate education from two perspectives: students and educators. Firstly, undergraduate students are given more autonomy in their learning, but such autonomy can lead to a lack of self-regulation of learning. Prompting students to reflect on their learning regularly can foster self-regulated learning (Zimmerman and Kitsantas 2005), thus preventing such situations. For example, students can review class materials that are particularly confusing or search for additional information regarding interesting concepts. Secondly, educators can leverage students’ reflections as diagnostic tools to assess their understanding of new concepts and identify areas requiring further explanation (Menekse 2020). This facilitates the adaptation of instructional strategies and the modification of teaching materials to address students’ needs or areas of interest. For example, after reviewing student reflection data, instructors may choose to post external online resources on a learning management system aimed at clarifying concepts that students found confusing. The advantages of the RILI model are particularly notable within the realm of engineering college education. This is attributed to the prevalent challenge faced in many college-level engineering courses, where instruction occurs within large class sizes, making it hard for instructors to monitor individual students’ learning progress. Several previous works in engineering education employed the RILI model in various contexts. They investigated its impacts on problem-solving processes in a physics course (De Laet, Sijmkens, and De Cock 2021), improvement in the quality of reflection in an interdisciplinary engineering program (Wilhelm 2021), engineering teachers’ instructional strategies (Eshuis, Mittendorff, and Daggenvoorde-Baarslag 2023), and academic performance in an industrial engineering course (Menekse 2020).

2 RELATED WORKS & RESEARCH QUESTIONS

The impact of reflection after learning on academic performance has been extensively studied, with research consistently highlighting its positive effects on students' academic performance. For example, a meta-analysis of 45 selected studies (Guo 2022) showed that the positive effect of metacognitive prompts on learning outcomes was consistent across undergraduate and K-12 students. Such studies were all experimental or quasi-experimental research but were limited to computer-based learning environments, excluding using digital tools in traditional classroom environments. Metacognitive prompts in this meta-analysis study include pre-learning (task perception, planning), during-learning (monitoring, control), and post-learning (evaluation, reflection). For example, Kauffman et al. (2008) showed that reflection prompts (i.e., questions designed to encourage students to reflect on how well they have solved problems and to evaluate and revise solutions when necessary) positively impacted problem-solving efficiency and writing quality. Another study by Wong et al. (2021) explored the impact of self-regulated learning (SRL) prompts, including reflection prompts, on students' engagement in SRL behavior and learning outcomes in Massive Open Online Courses. Results showed no significant impact on learning outcomes but a positive impact on SRL engagement.

Meanwhile, Menekse et al. (2022) compared the impact of generic and specific reflection prompts on engineering students' academic achievement in a course. Results showed that students who received the specific prompts performed significantly better on exams and projects than those who received the generic prompts. While numerous studies have explored the use of reflective prompts and digital tools in various educational settings, applying such methodologies to physics courses remains relatively novel. Regarding the impact of the number and quality of reflections, few studies have systematically tested these factors using robust models and indicators. Previous research (e.g., Menekse et al. (2022)) has examined the quality of reflections in general engineering contexts, but few studies applied multiple linear regression models to evaluate the predictive power of reflection quantity and quality, specifically in physics courses.

In higher education settings, technology-supported reflection on learning has gained significant attention as a means to enhance educational experiences. Various digital tools and platforms have been developed to facilitate reflection processes, enabling students to engage in metacognitive activities that deepen their understanding of course material and foster critical thinking skills. For instance, one design-based research by Leinonen et al. (2016) suggested two mobile apps for reflection (i.e., ReFlex and TeamUp). It showed their positive impacts on fostering K-12 students' classroom learning through reflective practices. They used the framework suggested by Fleck and Fitzpatrick (2010) to include various levels of reflection, from descriptive reflection (i.e., a mere description of events without further elaboration) to critical reflection (i.e., reflections with consideration of social/ethical issues). Another study by Knoth et al. (2020) explored how a mobile app named Reflect.UP promotes reflection at irregular intervals and its impact on students' learning experiences. This app was designed particularly to support student engagement during the introductory phase of a course by pushing reflective questions that refer to organizational knowledge (e.g., Where do I get a library card?), academic knowledge (e.g., How do I read a table?) and skills knowledge (e.g., Can I do what is required of me, and does

what is required fulfill my expectations?). The empirical results showed what skills students wanted to improve eventually and how they were satisfied with the app usage. Still, the use of mobile applications to support reflection in traditional classroom environments, particularly in physics courses, is underexplored. Our study is among the first to investigate the impact of reflection prompts delivered via a mobile app in an introductory physics course.

This research aims to explore the role of reflection-informed learning and instruction in students' academic performance in an introductory physics course. We narrowly define student reflection as reflections on interesting and confusing concepts that students learned in each lecture. We set our first research question as follows: RQ1) Did the students in the intervention group perform better than ones in the control condition? The intervention for promoting reflection is using a mobile application that prompts students to leave reflections after each lecture. Also, to further explore why promoting reflection can be helpful for academic performance, we set our second research question as follows: RQ2) Are the quantity and the quality of student reflection a significant predictor of academic performance? The two research questions are answered by employing a quasi-experimental research method where we collected and analyzed student reflection data from an actual physics course.

3 METHOD

3.1 Participant

Participants of this study were 199 engineering and science students at a public university in the Northeastern region of the United States. They were enrolled in the introductory physics course for science and engineering. The Institutional Review Board (IRB) approved the recruitment of participants. Only students who consented to have their grade information were included in the data analysis. There were two sections of the same class. Students in one section were assigned as the control group ($n = 105$) as they were not asked to reflect on their learning. In contrast, the students in the other section were assigned as the intervention group ($n = 94$) as they were asked to reflect on their learning after each lecture during an academic semester. The same instructor taught both sections using the same learning materials and assessment items (e.g., homework, exams, etc.)

3.2 CourseMIRROR App

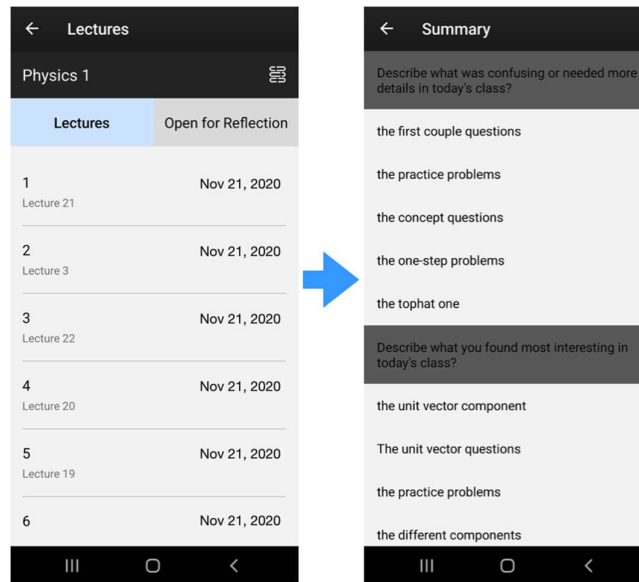


Figure 1. An example screenshot of the CourseMIRROR app.

CourseMIRROR (Mobile In-situ Reflections and Review with Optimized Rubrics) is a mobile application developed to prompt and collect students' self-reflection and in-situ feedback (Fan et al. 2015). This app collects data from student reflections to help instructors identify students' difficulties and provide additional feedback and support for student learning throughout the semester. Figure 1 shows an example of the app's user interface. On the left of this figure, students could choose one of the lectures of a course they are taking. After selecting one lecture, they were asked to answer two reflection questions, namely, 'Describe what was confusing or needed more details in today's class?' and 'Describe what you found most interesting in today's class?' Students were given a specified timeframe to submit their reflections on each lecture. Students and instructors could see the summarized list of responses for both questions, as seen on the right of Figure 1. Data collection through the app started after IRB approved the study. Students were encouraged to use the app, but it was not mandatory. Reflection data collected via this app was tracked only by the researchers, and we used anonymized IDs for each student who agreed to participate in the study. The instructor had access only to the summary of reflections that is automatically generated from the reflections.

3.3 Data Collection and Analysis

To answer RQ1, we compared the academic performances of the control and the experimental groups. The assumption tests (i.e., Shapiro test and Levene's test) revealed that both the normal distribution and the Homogeneity of variance assumptions were violated. Thus, we used the Kruskal-Wallis Rank-Sum test. The dependent variables were set as four measures of academic performance: the average of quiz scores, the average of homework scores, the average of exam scores, and the final score. The final score was calculated as a weighted average of the other variables based on the instructor's decision. The effect size and magnitude for each test were measured using eta-squared based on the H-statistic (Cohen 2013). To answer RQ2, we set predictors of academic performances as the number and the quality of student reflections. To calculate such predictors, we collected

student reflection data from the CourseMIRROR server. The number of reflections for each student was calculated as the average of the total reflections written in the entire semester. The quality of the reflections was measured through two variables: the specificity score of reflections on interesting concepts and confusing concepts. The calculation of the specificity score was based on the coding schema developed by the authors' previous works (Butt 2023, Menekse 2020), where NLP (Natural Language Processing) algorithm was used to rate reflection specificity on a 4-point scale from 1 to 4. Scores 1, 2, 3, and 4 indicated shallow reflection without a statement of confusion or interest, vague reflection, general reflection, and specific reflection, respectively.

For both groups, only students who agreed to share their academic performance were included in the data analysis. The reflection data was collected from students in the intervention group who agreed to participate in this study. Nine students did not leave reflections, so we imputed their reflection count and specificity scores using a missing data imputation method called MICE (Multiple Imputation by Chained Equations) following the recommendation by Peugh and Craig (2004) and Cheema (2014).

4 RESULTS AND DISCUSSION

4.1 RQ1

Table 1. Kruskal-Wallis Rank-Sum test results to answer RQ1

DV	Condition	Mean	SD	χ^2	p-value	Effect size	Magnitude
Quizzes	Control	87.95	11.10	16.77	< 0.001***	0.08	Moderate
	Intervention	92.98	3.94				
Home-work	Control	92.81	13.36	6.45	< 0.05*	0.03	Small
	Intervention	95.22	10.63				
Exams	Control	62.67	20.69	57.89	< 0.001***	0.29	Large
	Intervention	83.11	8.79				
Final Score	Control	77.81	13.43	33.29	< 0.001***	0.16	Large
	Intervention	87.28	6.14				

* $p < 0.05$, *** $p < 0.001$

Table 1 shows the Kruskal-Wallis test results to compare the academic performances between the control group ($n = 105$) and the intervention group ($n = 94$). Reflections were collected from 27 lectures for the intervention group. The average set of reflections was 7.43 ($SD = 5.80$). As one set of reflections means two written reflections, one on confusing and the other one on interesting concepts, respectively, the average total number of reflections is 14.86 written by 94 students. The intervention group showed significantly better academic performance for all four dependent variables than the control group, with the significance level being 0.05.

These results align with the literature reviewed in Section 2 that proved the positive impacts of reflection intervention on academic achievement. Our results provide

experimental evidence on the impacts of mobile-assisted learning, specifically within the relatively underexplored context of traditional STEM lecture-based courses, with even fewer focusing on physics education. Also, our results show that such impacts are effective not only in exam scores but also in ongoing academic performances, such as quiz and homework scores, despite the variation in the effect size.

In addition, the magnitude of effect size was large, particularly in exams, showing that reflecting on interesting and confusing concepts after each lecture positively impacted exam scores more than homework and quiz scores. Since homework and quizzes were conducted more frequently than mid-term and final exams, the positive impact of prompting student reflections might accumulate as students repetitively reflect, eventually becoming evident in exam scores. Future research may explore different measures of learning experiences other than academic performance.

4.2 RQ2

Table 2. Multiple linear regression results to answer RQ2

(a) Regression Statistics

<i>Multiple R²</i>	0.06
<i>Adjusted R²</i>	0.02
<i>SE</i>	6.07
<i>F</i>	1.75
<i>p value</i>	0.16

(b) ANOVA statistics (* $p < 0.05$)

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>p value</i>
Number of reflections	1	180.6	180.65	4.91	0.03*
Specificity of reflections on interesting concepts	1	5.8	5.85	0.16	0.69
Specificity of reflections on confusing concepts	1	6.9	6.88	0.19	0.67
Residual	90	3314.6	36.83		

(c) Coefficient of each predictor (* $p < 0.05$, *** $p < 0.001$)

Predictors	Coefficient	<i>SE</i>	Standardized coefficient	<i>SE</i>	<i>t</i>	<i>p value</i>
Number of reflections	0.25	0.11	1.46	0.64	2.28	0.02*
Specificity of reflections on interesting concepts	-0.35	1.33	-0.17	0.66	-0.27	0.79
Specificity of reflections on confusing concepts	-0.45	1.04	-0.29	0.66	-0.43	0.67
(Intercept)	88.24	5.13	87.28	0.63	17.19	0.00***

Table 2 shows the result of multiple linear regression to explore which aspects of student reflections are significant predictors of academic performance. The estimated regression equation to predict one student's total score for the semester is as follows: (Total score) = $88.24 + 0.25$ (Number of reflections) - 0.35 (Specificity of reflections on interesting concepts) - 0.45 (Specificity of reflections on confusing concepts). It turns out that the number of reflections was a meaningful variable to predict a learner's academic performance ($F(1, 180.6) = 4.91, p = 0.03^*$), despite the R^2 values being small. In contrast, the specificity of reflections was not. Such results were consistent for the other three dependent variables, i.e., quiz, homework, and exam scores.

Our analysis found that the more often students engaged in reflection after lectures, the more likely their academic performance would be high. This could indicate that even though students did not necessarily write high-quality reflections, the fact that they had time to reflect on their learning was sufficient for better academic performance. However, our result does not necessarily mean that the quality of reflections is less important than the number of reflections. Further research might investigate whether the specificity of reflections or another measure of the quality of reflections significantly impacts academic performances or may impact other parts of learning experiences.

5 SUMMARY

This quasi-experimental research explored the role of reflection-informed learning and instruction in students' academic performance in an introductory physics course. Regarding RQ1, results proved the positive impact of prompting reflections on all the measures of academic performance. Regarding RQ2, we conducted multiple linear regressions to examine whether the number and quality of student reflections are significant predictors of academic performance. It turns out that only the number of student reflections was a meaningful predictor. Despite our important findings, our study has a few limitations. First, as we decided to focus on academic performance only, we might have missed the positive impact of prompting student reflections on other aspects of learning experiences, such as motivation and engagement. Second, since we do not have any classroom observation data, there could be some factors that could have influenced students' reflection behaviors across two different sections. Third, as using the CourseMIRROR app was not mandatory, the average number of reflections was not high compared to the number of lectures.

Nevertheless, our study has a three-fold contribution to the engineering education community. First, our study extends the existing literature on the positive impact of prompting student reflection in learning to a relatively underexplored context of large-size, lecture-oriented classrooms commonly found in introductory engineering courses. Also, our study found that intervention in the form of encouraging students to reflect more often on their learning experiences can lead to improved academic performance. By evaluating both the quantity and quality of reflections, our research contributes new insights into how these aspects influence academic performance. Lastly, our study adds to previous findings on how a mobile application can be used to support reflection-on-action activities in a large-enrolment STEM course. While several studies explored the use of apps for reflection in various educational

settings, we uniquely investigated their application within a traditional, lecture-based physics course.

REFERENCES

- Allison, P. D. (2009). Missing data. *The SAGE handbook of quantitative methods in psychology*, 72-89.
- Boud, David, Rosemary Keogh, and David Walker. 1985. "Reflection: Turning Learning into Experience." *Kogan Page, London*.
- Butt, A., S. Anwar, and M. Menekse. 2023. "How Do NLP-Supported Scaffolding Techniques Support Students' Written Reflections?" In *INTED2023 Proceedings*, 7450–7450. IATED. <https://doi.org/10.21125/inted.2023.2036>.
- Cheema, J. R. (2014). "A review of missing data handling methods in education research". *Review of Educational Research* 84(4): 487-508. <https://doi.org/10.3102/0034654314532697>
- Cohen, Jacob. 2013. *Statistical Power Analysis for the Behavioral Sciences*. Routledge. <https://play.google.com/store/books/details?id=clJH0IR33bgC>.
- De Laet, Tinne, Elien Sijmkens, and Mieke De Cock. 2021. "Triggering Reflection and Meta-Cognition in Physics Problem Solving." In *Proceedings of the 49th Annual Conference of European Society for Engineering Education*, 180–88. Research Papers. <https://lirias.kuleuven.be/retrieve/642420>.
- Eshuis, Elise, Kariene Mittendorff, and Heleen Daggenvoorde-Baarslag. 2023. "Professionalising Science And Engineering Teachers In Guiding And Assessing Reflection." In *Proceedings of the 51st Annual Conference of European Society for Engineering Education*, 415–24. Research Papers. <https://doi.org/10.21427/5EV2-MP91>.
- Fan, Xiangmin, Wencan Luo, Muhsin Menekse, Diane Litman, and Jingtao Wang. 2015. "CourseMIRROR: Enhancing Large Classroom Instructor-Student Interactions via Mobile Interfaces and Natural Language Processing." In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, 1473–78. CHI EA '15. New York, NY, USA: Association for Computing Machinery. <https://doi.org/10.1145/2702613.2732853>.
- Fleck, Rowanne, and Geraldine Fitzpatrick. 2010. "Reflecting on Reflection: Framing a Design Landscape." In *Proceedings of the 22nd Conference of the Computer-Human Interaction Special Interest Group of Australia on Computer-Human Interaction*, 216–23. OZCHI '10. New York, NY, USA: Association for Computing Machinery. <https://doi.org/10.1145/1952222.1952269>.
- Guo, Lin. 2022. "Using Metacognitive Prompts to Enhance Self-regulated Learning and Learning Outcomes: A Meta-analysis of Experimental Studies in Computer-based Learning Environments." *Journal of Computer Assisted Learning* 38 (3): 811–32. <https://doi.org/10.1111/jcal.12650>.
- Kauffman, Douglas F., Xun Ge, Kui Xie, and Ching-Huei Chen. 2008. "Prompting in Web-Based Environments: Supporting Self-Monitoring and Problem Solving

- Skills in College Students.” *Journal of Educational Computing Research* 38 (2): 115–37. <https://doi.org/10.2190/EC.38.2.a>.
- Knoth, Alexander, Alexander Kiy, Ina Müller, and Mathias Klein. 2020. “Competences in Context: Students’ Expectations and Reflections as Guided by the Mobile Application Reflect.UP.” *Technology, Knowledge and Learning* 25 (4): 707–31. <https://doi.org/10.1007/s10758-019-09407-8>.
- Leinonen, Teemu, Anna Keune, Marjaana Veermans, and Tarmo Toikkanen. 2016. “Mobile Apps for Reflection in Learning: A Design Research in K-12 Education.” *British Journal of Educational Technology: Journal of the Council for Educational Technology* 47 (1): 184–202. <https://doi.org/10.1111/bjet.12224>.
- Menekse, Muhsin. 2020. “The Reflection-Informed Learning and Instruction to Improve Students’ Academic Success in Undergraduate Classrooms.” *Journal of Experimental Education* 88 (2): 183–99. <https://doi.org/10.1080/00220973.2019.1620159>
- Menekse, Muhsin, Saira Anwar, and Zeynep Gonca Akdemir. 2022. “How Do Different Reflection Prompts Affect Engineering Students’ Academic Performance and Engagement?” *Journal of Experimental Education* 90 (2): 261–79. <https://doi.org/10.1080/00220973.2020.1786346>.
- Owens, Melinda T., Shannon B. Seidel, Mike Wong, Travis E. Bejines, Susanne Lietz, Joseph R. Perez, Shangheng Sit, et al. 2017. “Classroom Sound Can Be Used to Classify Teaching Practices in College Science Courses.” *Proceedings of the National Academy of Sciences of the United States of America* 114 (12): 3085–90. <https://doi.org/10.1073/pnas.1618693114>.
- Schon, D. A. 1983. “The Reflective Practitioner: How Professionals Think in Action.” academia.edu. 1983. [https://www.academia.edu/download/55425701/The Reflective Practitioner How Professionals Th.pdf](https://www.academia.edu/download/55425701/The_Reflective_Practitioner_How_Professionals_Th.pdf).
- Wilhelm, Pascal. 2021. “Fostering Quality of Reflection in First-Year Honours Students in a Bachelor Engineering Program Technology, Liberal Arts & Science (ATLAS).” *Journal of Higher Education Theory and Practice* 21 (16). <https://articlearchives.co/index.php/JHETP/article/view/5184>.
- Wong, Jacqueline, Martine Baars, Björn B. de Koning, and Fred Paas. 2021. “Examining the Use of Prompts to Facilitate Self-Regulated Learning in Massive Open Online Courses.” *Computers in Human Behavior* 115 (February): 106596. <https://doi.org/10.1016/j.chb.2020.106596>.
- Zimmerman, Barry J., and Anastasia Kitsantas. 2005. “Homework Practices and Academic Achievement: The Mediating Role of Self-Efficacy and Perceived Responsibility Beliefs.” *Contemporary Educational Psychology* 30 (4): 397–417. <https://doi.org/10.1016/j.cedpsych.2005.05.003>.