

# Impact of Feedback Features on Students' Learning Strategies: A Systematic Literature Review

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**Abstract**—This Research Full Paper presents a systematic literature review on the impact of feedback features on students' subsequent learning strategies. Research indicates that providing quality feedback improves learning performance in higher education, namely in computing and engineering education. Framed by the self-regulated learning model, this enhancement results from the interplay of cognitive, metacognitive, motivational, and behavioral actions driven by feedback toward the learning goal. Such a combination of planned and selected actions is the learning strategy decision to direct the accomplishment of learning tasks. Insights of how feedback interventions lead to increased use of effective learning strategies have predominantly relied on qualitative data from self-reports. However, self-reports mainly reflect students' perceptions but cannot accurately capture the dynamic adjustments of learning strategies in the feedback process. With the growing use of learning management systems that can collect various learning analytics data, recent works have attempted to automatically generate personalized feedback based on mapping students' progress against pre-determined rules. Learning strategy alterations as a result of the various forms of feedback can be detected from the trace data. The findings of these studies provide evidence of how various feedback features are associated with the adjustment of learning strategies. This paper presents a systematic literature review that analyzes papers related to shifting learning strategies upon feedback provision to identify features that can trigger students' adoption of more effective learning strategies. The objective is to collect evidence to highlight feedback as more than information but a process to guide the proper use of learning strategies for better learning achievement. Our analysis shows a need for more studies to observe changes in learner actions due to feedback and discusses limitations in current works. With the rapid development of education data mining and deep learning models, the growing knowledge of feedback features can be potentially used with these computational models to generate learning advice to guide strategy changes for achieving better learning outcomes.

**Keywords**—*feedback, learning strategies, higher education, self-regulated learning, learning analytics*

## I. INTRODUCTION

Application of appropriate learning strategies can lead to performance improvement [1], [2]. However, studies revealed that students frequently underused the proper learning strategies. They needed to learn when, why, and how to apply a learning

strategy that was most effective for a particular learning scenario [3], [4], [5]. On the other hand, feedback as a means to enhance self-regulation, which leads to improved academic performance, has been widely studied [6], [7]. Such performance enhancement is the ability of an individual to monitor and make necessary adjustments to behaviors based on the given feedback. In general, people believe that performance enhancement is associated with factors such as timeliness, frequency, and quality of feedback. However, recent studies have revealed that students' ability to act upon feedback has been overestimated [8], [9]. Such failure to invoke the corresponding effective learning strategy selection has hindered the expected effectiveness of feedback. As a result, studies exploring feedback's role in triggering a change in learning strategies are still needed for feedback to live up to its aspirations. This understanding can provide insights into engineering and computing courses, such as introductory programming courses, where students often struggle to reach the expected learning outcomes. Effective personalized feedback that can provoke appropriate learning strategies can benefit students' widely different learning paces, which are common in such courses.

This paper performed a systematic literature review to analyze the papers related to a shift of learning strategies upon feedback provision to identify features that can trigger students' adoption of more effective learning strategies. It collected evidence from previous works to explore feedback features that can effectively guide behavioral change to adapt to more effective learning strategies. In addition, this review discusses the opportunities of deriving learning strategies from learning analytics data, points out limitations of current works, and provides suggestions for future work.

This report is organized as follows: Section II presents the background and related work on learning strategies and feedback. Section III describes the methodological procedures adopted in this study. Section IV reports on the results of identified feedback features and the learning strategies. Section V details the discussions of the findings. Finally, section VI concludes the analysis of this review and provides suggestions for future work.

## II. BACKGROUND AND RELATED WORK

### A. Learning Strategies

Learning strategies refer to the study methods used in the learning process to accomplish the learning goals. A learning strategy employs a series of actions to promote effective and efficient learning [10], [11]. The literature reported many ways to define learning strategies, from observable behaviors like simple retrieval tasks such as reading and memorizing to internal processing and thoughts involving planning and self-monitoring, purposefully deployed to foster learning achievements [12]. For instance, Zimmerman and Pons [13] reported 15 self-regulated learning strategies from their interview findings, being self-evaluation, organizing and transforming, goal setting and planning, information seeking, monitoring, environmental structuring, self-consequences, rehearsing and memorizing, seeking peers or teachers' assistance, reviewing tests, notes or textbooks, and others.

On the other hand, some studies classified such conscious effort to facilitate learning into four main categories of strategies: cognitive, metacognitive, management, and motivational [14], [15]. Task-specific activities that integrate new content into existing knowledge, such as organizing and transforming, rehearsal and memorizing, etc., fall into the category of cognitive strategies, whereas monitoring and planning to formulate future steps in the learning process are typical implementations of metacognitive strategies. Metacognitive strategies are higher-order internal processes that monitor and exercise active control over the application of cognitive strategies engaged in learning [16]. Management strategies refer to using resources, including effort, time, and structuring the learning environment. Motivation strategies are the instrument to enhance students' self-efficacy to attain a higher level of engagement in the task.

Learning strategies involve applying cognitive, metacognitive, and resource management behaviors that adapt to the specific objectives of each learning situation. Cognitive strategies involve study methods spanning various possible behaviors, from reading, memorizing, doing exercises, watching videos, participating in forum discussions, and learning collaboratively. The effectiveness varies depending on the learning task. For example, re-reading and highlighting are practical learning actions to acquire fundamental knowledge of a learning concept but might not be adequate for learning tasks related to analysis and evaluation. Competent effort and time management were strongly associated with academic achievement [17]. Likewise, students being instructed to activate their metacognitive strategies showed better performance [18]. Research in [19] reported that learning strategies were reliable predictors of students' learning outcomes. Hence, research effort is needed to investigate the factors that can trigger the employment of these effective learning strategies toward optimal learning outcomes.

### B. Feedback

Feedback, one of the most influential factors in learning accomplishment, is a central part of learning. Feedback informs students on their performance and can include suggestions to invoke monitoring and guide future behavior for improvements [20], [21]. There is extensive research on the positive association

of feedback with academic achievement, with studies approaching from different perspectives. For instance, some studies looked at performance-based feedback on the students' strengths and weaknesses in the taught subject. Other studies explored feedback practice on the self-regulated learning process to provoke self-monitoring and engagement aspects. In addition, some studies focused on delivering learning advice feedback recommending learning actions to be applied as the next step in the learning process. In contrast, some studies investigated feedback delivery mechanisms such as timeliness, conciseness, frequency, content, quality, etc. The existing literature has extensively derived the associations of such feedback with academic performance. However, more research is still needed to consider the impact of feedback on the choices of learning strategies. Understanding students' responses to feedback regarding the adaptation of learning strategies offers promising opportunities to uplift the potential of feedback to optimize these learning strategy decisions.

## III. METHODOLOGY

This systematic literature review follows the guidelines of Kitchenham's methodology [22] to gather and assess the available evidence to answer the proposed research question. The details of the phases are described below.

### A. Research Question

The following research question was developed to collect evidence about the impact of feedback features on students' subsequent adoption of learning strategies: *What feedback features contributed to learning strategy decision changes?*

### B. Keywords and Database Definition

This review reports results according to PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines, as indicated in Fig. 1. The search strategy was performed in January 2024 in Web of Science (WoS), IEEE Xplore Digital Library, and ACM Digital Library databases. We did not filter papers by date and considered published results until January 2024. To cope with the scope of this study, we searched for the keywords [feedback AND "learning strateg\*"] in the abstract AND ["higher education" OR undergraduate] on the full text of papers in the databases.

WoS database returned 180 results, IEEE Xplore Digital Library returned 60, and ACM Digital Library returned 21. After removing 7 duplicates and adding 3 more papers identified from the references, the abstracts of 257 papers were scanned to identify possible relevant papers for detailed reading.

### C. Inclusion and Exclusion Criteria

To evaluate whether a paper meets the inclusion criteria, the preliminary step was to examine the title and read the abstract to determine the research objective of the work. Out of the 257 papers initially identified from the search result, the full papers of 38 studies were then sought for retrieval after abstract screening. Two of the papers could not be retrieved, leaving 36 papers to be assessed for eligibility. These papers were then reviewed against the inclusion and exclusion criteria.

The inclusion criteria are as follows.

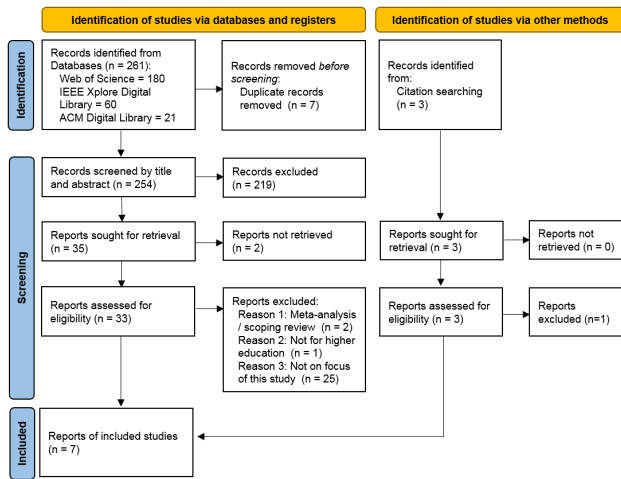


Fig. 1. PRISMA Flow Diagram

- The paper discusses the change in learning behaviors upon feedback.
- The paper discusses the impact of feedback on learning strategies.
- Both journal and peer-reviewed conference papers can be included.

The exclusion criteria are listed below.

- The paper is a meta-analysis or scoping review.
- The paper is not related to higher education.
- The paper covers feedback and learning strategies but without any associations between them.

TABLE I. DESCRIPTION OF 7 STUDIES INCLUDED IN THE FINAL SYNTHESIS

Study	Description
[23]	Surveys and focus group interview data were analyzed based on Bégin's taxonomy to identify the learning strategies reported by the students. Feedback included expert response choices and their explanations of the responses. Results showed that experts' feedback had an impact on cognitive strategies.
[24]	Individual semi-structured interviews were conducted with the students to collect data on why and how they used feedback. Participants described incorporating feedback into adapting strategies and modulating learning goals via motivation and effort investment.
[25]	Questionnaires were conducted to compare the application of cognitive, metacognitive, and resource management strategies between the control group and the intervention group, which was given daily personalized feedback representing the intensity of use of various strategy types as well as reminder messages. Results showed that such personalized feedback promoted metacognitive and resource-management strategies.
[26]	Based on data collected from learning management systems (LMS), automatic personalized feedback with cumulative grades, forecasted grades, reminders, and contribution scores was generated. Students reported the positive influence of feedback on their learning strategy via surveys. In addition, data from LMS after feedback dissemination recorded increased students' contribution rate.
[7]	The study used LMS trace data to detect learning strategies and automatically generate personalized feedback based on a student's level of engagement and performance. The results showed that personalized feedback with elaborated learning advice was positively associated with the application of learning strategies.
[27]	The study used LMS trace data to detect time-management-related learning strategies and generate feedback based on students' level of engagement with the pre-class learning activities. The results showed that feedback intervention could support students' time management strategies.
[28]	Focus group sessions were conducted to explore how students perceive personalized feedback. The results of this study indicated the effective features of learning analytics-based feedback that were influential to students' subsequent adoption of self-regulated learning processes. From the student's perspective, effective feedback increased motivation, reduced procrastination, and enhanced goal-setting.

- The paper explores learning strategies and collecting feedback as a response.
- The paper investigates giving feedback on learning strategies and their association with self-efficacy, motivation, etc.

During this inclusion and exclusion process, text searches were performed to locate the paragraphs that contain the searched keywords. These paragraphs were read to decide if the paper was relevant to the impact of feedback on learning strategies. We omitted works that are meta-analyses or scoping reviews, covering feedback and learning strategies as two individual concepts without any associations between them as the main contribution, exploring learning strategies and collecting the feedback as a response, etc. After carrying out the inclusion and exclusion criteria, 7 papers were included in the final synthesis to extract data for this literature review. For an overall description of these 7 papers, see Table I.

#### IV. RESULTS

This section discusses the results of synthesizing the papers for the systematic literature review. Seven studies were included in the final review based on the inclusion and exclusion criteria. Table I presents a brief description of these studies.

These papers identified feedback features to consider how such feedback intervention can stimulate learning action alterations and learning strategy decision changes. The identified feedback features and the resulting changes in learning actions, as well as the adaptation of learning strategies of the papers, are presented in Table II. Some studies used several feedback features in the intervention process to activate the resulting changes in learning strategies.

A wide-ranging list of possible feedback features was investigated regarding the effectiveness of feedback in the literature. Studies on the association of feedback with performance have looked at features including, but not limited to, timeliness, frequency, conciseness, quality, content, etc. However, in this review to explore the impact of feedback features on the changes of learning actions and strategies, these 7 reviewed papers have instead set focus on three of the four levels of feedback messages as described by Hattie and Timperley [20], namely, task level, process level, self-regulation level and self level. Task level feedback denotes how well tasks are performed in terms of performance. Process level feedback refers to the process needed to understand and perform the tasks, and learning advice feedback is an example of such implementation. Self-regulation level feedback helps learners to engage through self-monitoring and regulating the learning strategies accordingly, whereas self-level feedback refers to comments about the learner. 71.4% of the reviewed studies investigated engagement-based feedback, 42.9% performance-based feedback, and 28.6% process-level feedback. Self-level feedback was not covered in any of these studies, and this followed the conclusion by Hattie and Timperley that self-level feedback is the least effective.

## V. DISCUSSION

While feedback can stimulate change and the adoption of appropriate learning strategies, it is also an intervention with significant variance in effectiveness. Based on the abundance of literature to tackle the effectiveness of feedback from various perspectives, there is no one-fits-all solution in terms of feedback. The characteristics of effective feedback will change across different learning scenarios. Hattie and Timperley [20] concluded that feedback at the self-regulation and process levels is generally most effective in promoting learning gains. Self-regulation feedback stimulates students to reflect and evaluate their current progress to facilitate the selection of learning strategies, whereas process-level feedback includes feed-forward hints that prompt students to the specific learning strategies to complete the task. We will discuss the various empirical evidence from the 7 reviewed papers that feedback triggers learning strategy decision changes.

### A. Engagement Feedback

Many studies covered in this literature review with engagement-based feedback are indeed feedback at the self-regulation level to stimulate students to monitor and adjust their behavior for learning improvements. For example, research in [26] presented students' engagement in terms of contribution scores derived from the frequency of activities detected from LMS, including the amount of time spent on the course

TABLE II. FEEDBACK FEATURES AND CORRESPONDING ADAPTATION OF LEARNING STRATEGIES. (\* COG = COGNITIVE STRATEGIES; MCOG = METACOGNITIVE STRATEGIES; RM = RESOURCE MANAGEMENT STRATEGIES)

Feedback features	Study	Description	Learning actions / strategies adaptation*		
			COG	MCOG	RM
Engagement feedback	[26]	Personalized feedback in the form of contribution score calculated from engagement factors derived from learning analytics, including time spent on course materials, number of questions asked and answered, etc. Such feedback triggered enhanced participation, as reflected by higher contribution rates, showing more effort and time spent learning.			✓
	[27]	Weekly personalized feedback based on the learner's level of engagement from time-management behavior as derived from learning analytics. A significant increase in the proportion of students adopting more competent time management strategies was recorded.			✓
	[28]	Feedback was generated based on learning management system activity and engagement, assessment, and attendance. Survey data reported an enhancement of reflection, increased motivation, and reduced procrastination, which can be considered indicators of metacognitive and resource-management strategies.		✓	✓
	[25], [26]	Students who had not accessed the required material within a period received feedback in the form of reminder messages. Such feedback acted as an alert for engagement, invigorating the effort and time spent learning.			✓
	[24]	Results from semi-structured interviews described incorporating supportive and constructive feedback into modulating learning goals via motivation and effort investment and adapting strategies with more planning and studying.	✓	✓	
Performance feedback	[26]	Personalized feedback includes cumulative grades and forecasted grades for students' progress and performance. Students commented that the forecasted grades impacted their learning strategies.		✓	
	[25]	Daily feedback reflecting the intensity of use of the various strategy types on the previous day was provided. Findings suggested that this approach promoted self-monitoring and self-regulation behaviors.		✓	
	[7]	Class average score is part of the feedback components for students to reflect on their performance. Metacognitive actions were detected from LMS trace data.		✓	
Learning advice feedback	[7]	Elaborated learning advice feedback focused on the study activities and extra learning materials. LMS trace data detected an increased number of students adopting various learning tactics. This could be seen as their process to self-regulate their learning.	✓	✓	
	[23]	Expert feedback was incorporated, including explanations and further resources for consultation. Qualitative data collected presented evidence that experts' feedback had an impact on cognitive strategies and prompted students to self-monitor their knowledge.	✓	✓	

materials, the number of questions asked, the number of answers given to the questions of other students, etc. Such an engagement index provided a means for students to self-monitor and evaluate their degree of participation, interaction, and involvement. Research [26] was carried out in online introductory computer science courses with attempts to retrieve the most out of the real-time evidence on students' daily learning activities tracked through the LMS. According to [29], participation/interaction/involvement was ranked first among the top ten student engagement indicators. The contribution score of [26] implements this indicator, capturing the students' effort in learning. The contribution score, together with the reminder messages of [26], presented multiple sources of indicators to foster students' self-regulation to improve engagement. The self-reflection process can trigger strategy selection decisions toward the learning goal. The resulting improvement of contribution score after feedback delivery provided evidence that self-regulation level feedback improves observable levels of engagement changes with enhanced participation rate. Such increased time and effort spent on learning is an example of a resource-management strategy.

Reference [27] detected students' time management strategies from LMS trace data about students' interactions with learning activities. Based on the time students performed the actions in the LMS, the learning actions were associated with different study modes: preparing, revisiting, ahead, and catching up. Through the lens of such classification, how students self-regulated in organizing their learning at their own pace could be observed, whether they were starting ahead of scheduled topics, accessing the course material in preparing mode just before the designated class schedule, reviewing materials after class time for catching up or revisiting the learning material for revision purpose. This study presented another perspective to observe and represent students' engagement and self-regulation level. Results of this study showed that after feedback intervention, the proportion of mid-performing and poorly performing students dropped. In contrast, the proportion of students in the high-performing group increased significantly, indicating that feedback reporting level of engagement from time-management behavior can stimulate the adaptation to a more competent time-management strategy.

Feedback from two of the reviewed studies was in the form of reminder messages to students when they did not access the required material within a period [25], [26]. This kind of feedback effectively activated the engagement by reminding students of their status and stimulating participation in learning behaviors, triggering changes in increased effort and time spent on learning. Data collected from questionnaires [25] confirmed that the interventions promoted resource-management strategies, whereas the contribution score derived from LMS data was increased, suggesting more engagement of time and effort in the learning process [26].

Spooner et al. [24] conducted semi-structured interviews to explore how feedback influenced medical students' self-regulation of learning. Students described incorporating positive and supportive feedback into adapting strategies, while negative feedback was often not actioned upon. Disengagement due to negative feedback affected learning outcomes. In this study, supportive and constructive feedback promoted affective

engagement, encouraging positive motivational beliefs to stimulate behavioral changes. Supportive feedback keeps students engaged in the learning process. It enables learners' self-regulation by applying behavioral changes in response to learning information while, at the same time, modulating their knowledge and beliefs on the learning process to change their cognitive strategies for learning enhancement. Students reported investing more effort in planning and studying when feedback was constructive.

Lim et al. conducted focus group sessions to examine how students made sense of feedback to adapt self-regulated learning processes [28]. Feedback was generated from learning management system activity, engagement, assessment, and attendance. The results indicated that personalized feedback helped students refine or strengthen goal-setting and reduce procrastination. These were indicators of having applied metacognitive strategies and resource management strategies.

The findings above aligned with Hattie and Timperley's conclusion [20] that feedback at the self-regulation level encourages students to monitor their current progress to facilitate the selection of learning strategies, thereby closing the gap between the current and expected learning outcomes. Most studies with engagement feedback recorded an adaptation of resource management strategies involving decisions and intentions of allocating time and effort to studying. Efficient time and effort management had a positive association with academic performance [17]. Hence, promoting resource management strategies is particularly important for students' academic performance.

### *B. Performance Feedback*

Performance feedback informing students of "How do I perform?" allows students to monitor and track their learning progress. Such performance indicators develop an awareness of their learning progress and redirect students' actions to achieve the learning goal. In [25], graphic feedback representing the intensity of use of the various strategy types on the previous day was provided, articulating task performance criteria as a basis for appropriate learning strategy selection and acting as a means to promote self-monitoring and self-regulation. Data collected from the questionnaires confirmed that the interventions promoted metacognitive strategies. Self-monitoring and self-reflection processes are applications of metacognitive strategy [30].

Research in [26] provided students with their current standing via cumulative grades and visualized progress forecasting, a predicted projection of the final achievement based on the current performance. Students reported that the forecast motivated them to alter their learning strategy toward a better learning outcome, as confirmed by the drastic change in performance improvement. Although the qualitative data as reported by the students only referred to their perception regarding the positive influence of feedback on their learning strategy in general, we suggest that the cumulative grades and forecasted grades can trigger students' reflection on the evidence of learning as illustrated by the descriptive side of the feedback [31]. From this perspective, it indicates changes in metacognitive strategies for self-monitoring.

Personalized feedback reporting students' performance, together with the average performance of the cohort, enhances students' awareness of their current progress. This piece of descriptive information regarding learning performance depicts the gaps between students' expected and actual performance to drive changes in learning strategies by applying metacognitive actions to improve performance [7].

Performance feedback can be effective by informing students of their progress and allowing them to monitor the performance gap between the goal and progress. All three reviewed papers that provided performance feedback reported on adapting metacognitive strategies. However, to a certain extent, performance feedback is also a double-edged sword. Students not performing well compared to the overall cohort's average performance might choose to disengage due to frustration, opposition/rejection, disappointment, and other affective disengagement, as reported in [29]. This "emotional backwash" can hinder their cognitive processing of the developmental information [32], and it may increase the dropout rate too [33]. Performance feedback is more than simply an indicator of the outcome. Its purpose is to have students recognize the gaps in their knowledge, intended to adjust the learners' behavior to improve their performance [34]. There is an affective dimension to receiving feedback. Students need to feel valued and involved. Otherwise, they will fail to make the most of the feedback opportunities. To avoid leaving low-performing students behind, studies examined introducing additional interventions to motivate and engage these students, for example, to participate further in online discussions [26] or to reiterate the implementation of learning strategies [3]. Students felt more motivated to respond to feedback with such interventions. Results of these additional interventions provided insights on the need to take care of affective engagement of performance feedback to prevent feedback not being acted upon, rendering feedback to simply a piece of information, offsetting its intentional purpose to improve performance in the learning process.

### C. Learning Advice Feedback

Good feedback enables students to reflect upon their work and provide information on where to act for improvement [35]. In line with Hattie and Timperley's research [20], beneficial feedback should address the next steps in learning and may lead them to choose different strategies for future learning [36]. Advising students on strategically using learning resources promoted learning enhancement [37].

Research [7] was conducted on first-year computer engineering flipped classes, with LMS trace data collected from the online pre-class activities. Learning advice was elaborated on the study activities, and extra learning materials were provided as feedback to the students every week. Based on LMS data analytics, an increased adoption of various learning tactics could be detected after feedback delivery, suggesting changes in cognitive strategies. The study stated that students using a variety of learning tactics could be regarded as their process to self-regulate their learning [38]. According to [30], this is relevant for metacognitive strategy application. This pattern of a repetitive weekly cycle of preparation tasks followed by elaborated learning advice feedback and performance feedback

aligns with Zimmerman's cyclical phase model of self-regulated learning [39], covering forethought, performance, and self-regulation. The elaborated learning advice guided students to observe and focus on the goals, and the performance feedback triggered the metacognitive awareness to self-regulate and adapt strategies.

Research [23] incorporated expert explanations and further resources for learning in the feedback. Qualitative data collected from the study reported that such feedback stimulated students' cognitive and metacognitive strategies. Students took metacognitive actions to make regulations to modify their cognitive actions to address their shortcomings toward the learning goal orientation.

Both reviewed papers providing learning advice feedback reported on adapting cognitive and metacognitive strategies. Knowing when, where, and how to apply learning tactics and strategies is the catalyst to enhance learning [40]. However, studies have shown that students often need more skills to adjust their learning strategies to meet the requirements [41]. Effective feedback tells students how they should direct their subsequent efforts and how they performed [21]. Learning advice feedback can bridge the gap between current progress and expected learning achievement by providing "How can I do better?" recommendations to give clear directions on what can be done. These helpful, actionable recommendations set a path for students to follow so that they can take action accordingly and effectively augment their current learning behaviors. This resonates with students' comments in [28] regarding feedback should be clear about future tasks, and in [24] that they struggled to generate learning strategies and expected teachers to make sense of the "how" in addition to "what" in planning future learning. Learning advice feedback can reorient their focus on areas for improvement and connect them with future learning opportunities.

## VI. CONCLUSION

Knowing when and how to employ a learning strategy for a learning scenario is crucial for learning accomplishments. Feedback is an essential factor in the learning process; when applied strategically, it can provide guidance on the appropriate implementation of learning actions, which can effectively trigger students' self-monitoring and self-reflection to activate their cognitive reactions and other internal processes, leading to possible improved achievement. This academic enhancement results from the interplay of cognitive, metacognitive, and resource-management strategies. Effective feedback toward the learning goal can drive these self-regulated learning components.

Effective feedback steers toward refocusing on goals, informing current performance related to goals, and advising on actions to bridge the discrepancy between goals and current performance [20]. Many studies provided findings as evidence that feedback can foster academic achievement. However, studies on the effectiveness of feedback features to induce students to adjust subsequent learning strategy selections are still scarce. Little is known about what feedback features can effectively affect students' learning strategy choices. This review paper has attempted to answer this question and presented evidence of the changes in learning strategy decisions

based on engagement, performance, and learning advice feedback. However, the small number of papers related to this topic poses a limitation. The lack of prior research might have an impact on the outcomes of this study. This implies that more studies on how these feedback interventions trigger learning strategy adaptation are still needed.

Another limitation is the major reliance on self-reported data in the identified papers for this study. Changes in learning strategies have predominately been captured via qualitative studies looking at students' perceptions. However, this approach cannot fully capture the dynamic alteration of learning strategy upon feedback delivery. The lack of evidence about the learning strategies that students have applied and changed due to feedback might be one of the underlying reasons for the small number of studies found regarding the impact of feedback on adopting learning strategies. Research into using LMS trace data to detect learning strategies has gradually increased. A growing number of studies have explored various combinations of data mining and machine learning algorithms to detect learning strategies based on students' interaction with activities performed via LMS [41], [42]. The findings of these studies presented a mechanism for researchers to track students' changes in learning actions in response to feedback. This observation enables researchers to better understand the feedback process and the extent to which the given feedback stimulates learning strategy choices. Such knowledge is of great value as it allows instructors to provide highly efficacious feedback that can successfully trigger the adoption of more effective learning strategies to boost student performance.

While performance and engagement-based feedback can be used with education data mining techniques, process-level feedback can be further leveraged with process mining tools to obtain insights for improving educational processes [43]. This is particularly helpful to students as they can follow the learning advice to proceed to the next step without the struggle to identify what needs to be done. This actionable learning strategy advice can support students to connect with future learning opportunities. In addition, tailor-made visualizations can purposefully assist with the understanding of student performance [44]. With the rapid development of education data mining, deep learning models, and visualization tools, the growing knowledge of feedback features can potentially be used with these computational models to produce learning advice that students can action to achieve better learning outcomes.

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